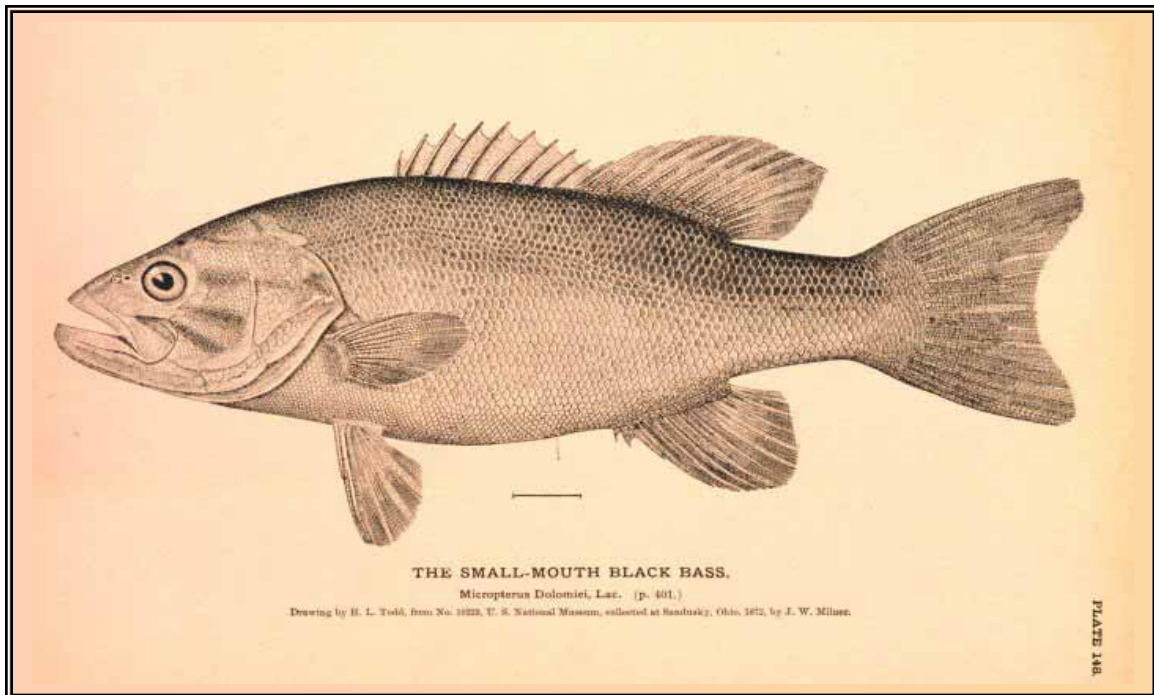


# **Best Management Practices for Finfish Aquaculture in Massachusetts**



**Western Massachusetts Center for Sustainable Aquaculture**

*University of Massachusetts Extension*

**UMass Extension Publication AG-BPFA**

## **Acknowledgements**

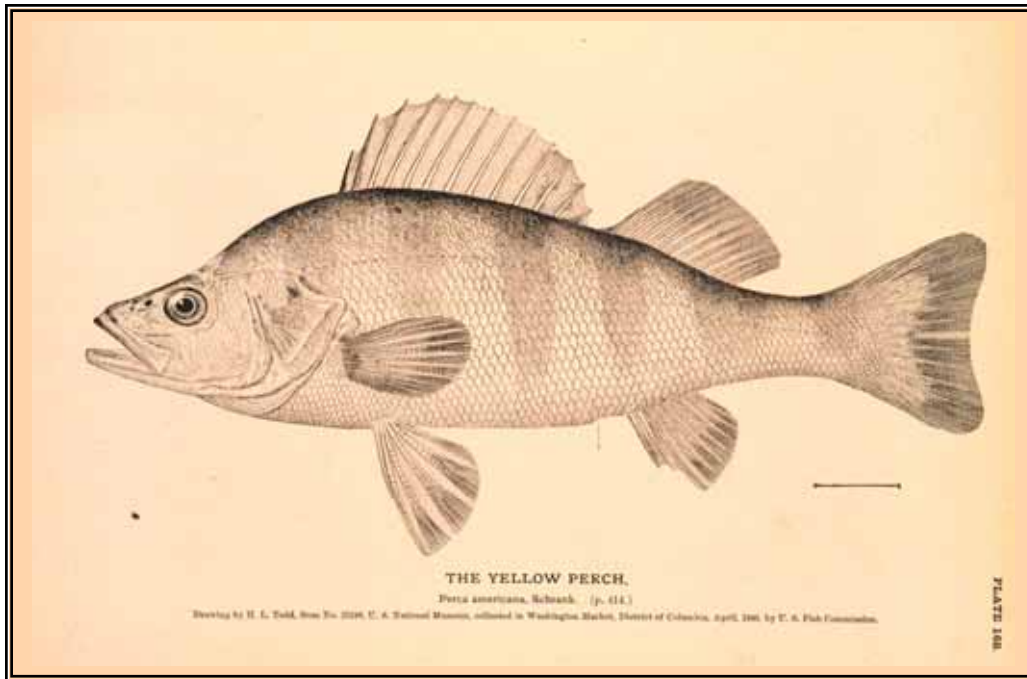
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# **Best Management Practices for Finfish Aquaculture in Massachusetts**



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*An electronic version of this manual can be accessed through [www.umass.edu/aquaculture](http://www.umass.edu/aquaculture)*

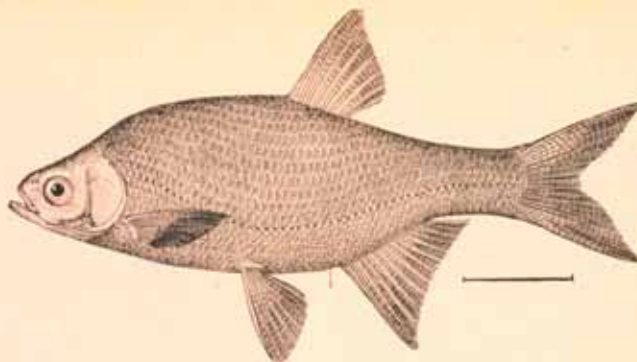
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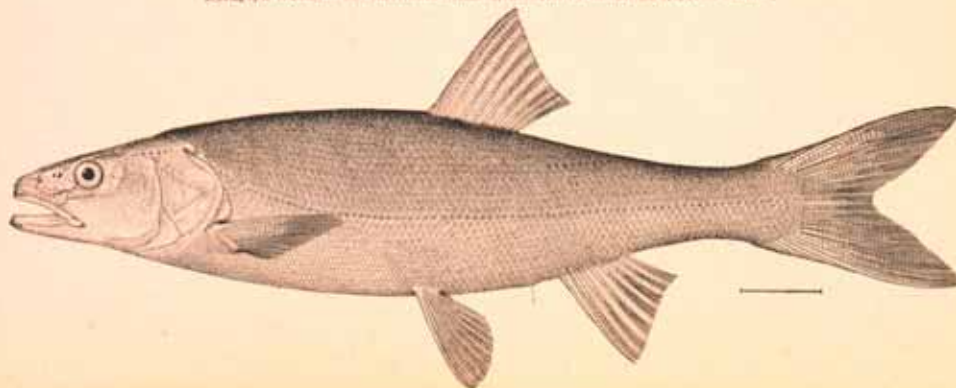
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THE GOLDEN SHINER OR BREEM.

*Notemigonus crysoleucas* (Mitch.), Jordan. (p. 616.)

Drawing by H. L. Todd, from No. 10241, U. S. National Museum, collected at Harkness's River, 1878, by Prof. S. F. Baird.



THE SACRAMENTO "PIKE."

*Psychrolutes argenteus* (Rich.), Grd. (p. 616.)

Drawing by H. L. Todd, from No. 12280, U. S. National Museum, collected at Columbia River, 1885, by Prof. D. S. Jordan.

# INTRODUCTION \_\_\_\_\_ Chapter 1

Aquaculture is the farming of aquatic organisms in natural or controlled marine or freshwater environments. There is a great diversity of activities and industries covered under this broad definition, but the discussion in this manual is restricted to the production of freshwater finfish in Massachusetts.

Aquaculture plays an increasingly important role in the Commonwealth of Massachusetts and in the United States. At present, the value of aquaculture products imported to the United States ranks third, following petroleum and automobiles, and the industry itself is growing as both small operations and large facilities are established.

In Massachusetts, finfish are grown for food and bait, for stocking into rivers, lakes and ponds, for research and instruction and for gardeners and hobbyists. While management and permitting requirements differ among the different types of aquaculture systems, pond culture, flow-through systems and recirculating systems, all production systems share the same environmental concerns: water use and discharge, land use, waste discharge, and the prevention of introduction and spread of invasive species and disease.

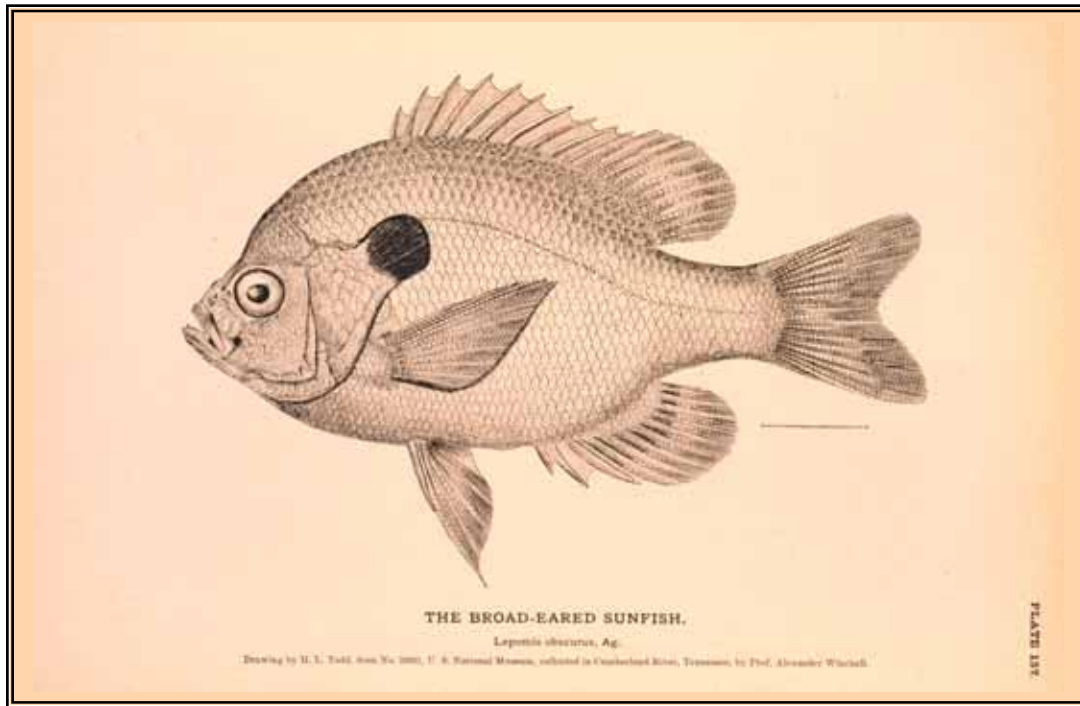
**Aquaculture is agriculture.**

USDA Farm Service Agency

**The practices listed in this manual are intended to assist finfish growers in improving production while preventing or minimizing environmental impact.** Best Management Practices (BMP) have a number of uses. They can guide those starting aquaculture projects, expanding or updating facilities, or growers maintaining present operations. We suggest that growers use this manual to conduct audits of their facilities to determine where improvements can be made. Growers may use these guidelines to develop their own farm-specific Standard Operating Procedure (SOP) manual. SOPs provide details about the conduct of significant farm practices. An SOP manual is not required for all farms, but the development of farm specific procedures will promote efficient management decisions when trouble shooting problems, training employees or planning future expansions. The manual can also assist growers in developing other plans for their operations, such as biosecurity plans and emergency procedure plans. Anyone contemplating fish farming should develop a business plan. Producers of food products should also prepare Hazard Analysis and Critical Control Point (HACCP) plans: internet links on this topic are provided in the Reference section (Chapter 8).

The BMP outlined in this manual can also assist federal, state and local agencies in understanding and evaluating proposed and existing aquaculture facilities to evaluate the suitability, feasibility and support of proposed projects.

*The aquaculture industry is carefully regulated in the Commonwealth of Massachusetts. Appropriate permits are required for building and modifying systems, water use and discharge, importation, transport and culture of fish and other regulated activities. See Permits and Regulations are discussed in Chapter 6 of this manual.*





# **General Aquaculture Practices \_\_\_\_ Chapter 2**

## **General Aquaculture Practices - Fish Health**

### **Management Considerations**

Starting with healthy fish minimizes the likelihood of severe disease outbreaks; fish should be obtained from a reputable supplier and quarantined when they arrive at the aquaculture facility. Stress, whether from environmental conditions, handling or predators should be minimized. Excessive handling or long distance transport cause added stress and increase the risk of disease outbreak. Water quality should be monitored and high quality feeds should be used.

### **Fish Health Issues**

- Receiving disease-free fish
- Predator pressure or stress
- Transportation and handling stress

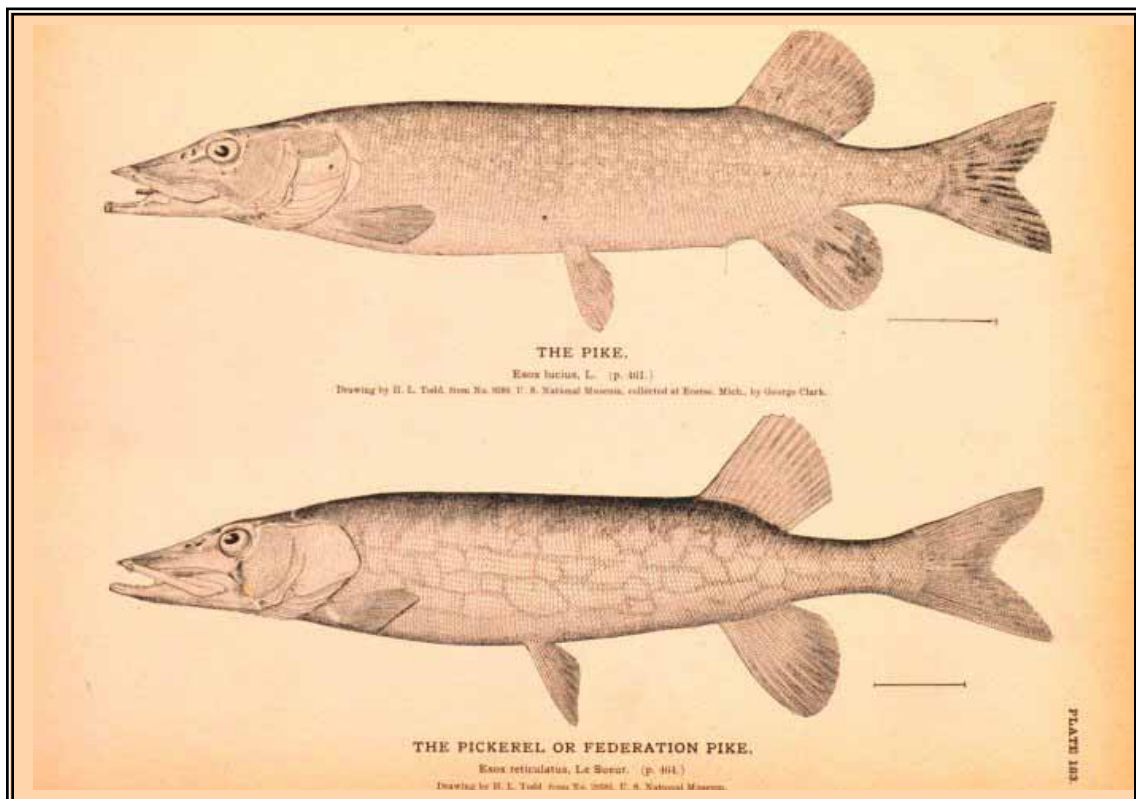
For a disease to occur, three criteria must be realized: fish must be susceptible to the disease, the disease must be present, and environmental conditions must be conducive for the pathogen. By utilizing clean or vaccinated fish, employing good management practice and maintaining good water quality the culturist can preclude or diminish the likelihood of a disease event. Disease outbreaks are more likely in fish under stress. Stress can be reduced by starting with healthy stock, handling fish properly, maintaining proper water quality, controlling predators, and constantly monitoring for disease.

To maintain a healthy culture environment, it is essential to start with healthy fish. Growers should request that fish are tested for appropriate diseases before receiving them from another hatchery. Disease inspection permits are required when importing fish from out of state. Different species have different tolerances to disease and disease affect cold water species and warmer water species differently. Growers should familiarize themselves with potential diseases (viral, parasitic, fungal or bacterial) that their fish species may contract and fish should be observed frequently for changes in physical appearance or behavior. Establishing rapport with a trained fish pathologist before a disease outbreak occurs is recommended. Samples should be sent to professional pathologists when a question of disease arises.

Predator access to the system should be eliminated wherever possible. Predators not only eat fish stock but their presence increases stress to the fish. They may also vector disease.

## Best Management Practices

- Fish must be obtained from reputable, experienced, disease-free hatcheries.
- Health inspections and certification of their absence for diseases that are relevant for the cultured species should be obtained.
- Fish should be inspected for signs of stress before introducing them to the system.
- Fish should be quarantined and acclimated with water from the new system before introduction into production units.
- Fish should be transported using industry standard stocking densities and water quality parameters for the species cultured.
- Fish health should be monitored visually and fish health experts contacted if questions arise. It is prudent to establish relationships with fish health experts before a disease outbreak to expedite shipment, diagnosis and treatment.



## **General Aquaculture Practices – Aquaculture Chemicals**

“Guide to Drug, Vaccine, and Pesticide Use in Aquaculture” was extensively used in the development of this section. See: <http://aquanic.org/jsa/wgqaap/drugguide/drugguide.htm>

### **Management Considerations**

Chemicals are used to control or prevent specific diseases, water quality conditions, and pest or stress problems. Wherever possible non-chemical practices are used to maintain appropriate conditions, as chemicals are expensive, their use in water systems can trigger additional regulatory and reporting requirements, and the conditions where chemicals are needed may be stressful to fish. However, sometimes chemicals are required to maintain health and productivity. Aquaculture chemicals include disinfectants, pesticides, drugs, and vaccines

While protecting the health of fish stocks is at the forefront of producers’ goals, the use of chemicals introduces the possibility of the introduction of harmful substances into the food chain and contamination of waters downstream from production facilities. To eliminate these risks, it is imperative that producers only use products that are legally registered for aquacultural use and the intended site, and that these products are used as specified by the label.

### **Aquaculture Chemical Issues**

- Avoiding the contamination of the human food chain
- Avoiding the contamination of the environment
- Optimization of chemical efficacy

The use of drugs and chemicals by the US aquaculture industry is strictly regulated by the US Food and Drug Administration (FDA, see References, Chapter 8) and the US Environmental Protection Agency (EPA). Pesticide use is regulated by the Massachusetts Department of Agricultural Resources (MDAR, see References, Chapter 8). Some disinfectants are registered as pesticides, thus are regulated by MDAR.

Disinfectants are a common disease management tool used to eradicate or exclude specific diseases from aquaculture facilities and as a routine sanitary measure to reduce disease incidence within aquaculture facilities. There is a great variety of products and procedures for washing and disinfecting installations or equipment used in aquaculture establishments or for treating effluents, and wastes from quarantine and processing plants. The decision on which product to use should take into account their efficacy, their safety for aquatic animals and the environment. A cost/benefit analysis may indicate that it is more economical to let disease run its course. ([http://www.aphis.usda.gov/NCIE/oie/pdf\\_files/aahc\\_gen-rec-dis-1-05.pdf](http://www.aphis.usda.gov/NCIE/oie/pdf_files/aahc_gen-rec-dis-1-05.pdf))

Pesticides are used to kill species that interfere with production, such as problem weeds or rodents, or insects and diseases of surrounding turf, crops or plantings. The use of restricted-use pesticides requires an applicator license, issued by MDAR. General-use pesticides can be used in most cases without an applicator license, however when pesticides

are applied into water additional regulations may apply, including Department of Environmental Protection regulations, EPA National Pollutant Discharge Elimination System (NPDES) requirements and rulings by local conservation commissions

There are a small number of drugs approved for use in aquaculture in the U.S. A listing of them is available at: <http://www.fda.gov/cvm/aqualibtoc.htm>. Antibiotics are only approved to treat disease and cannot be used to prevent disease or to promote growth. All drugs must be used according to label instructions.

Some chemical products are approved only for use with non-food fish or for certain life stages of aquatic species. The use of products may also be restricted to specified aquatic sites (for example, drainage ditches) rather than sites containing aquatic food species. For some fishes commonly cultured in Massachusetts, no approved drugs are available.

**IT IS THE USER'S RESPONSIBILITY TO KNOW WHETHER A PARTICULAR PRODUCT IS APPROVED FOR AN INTENDED USE IN AQUACULTURE AND TO USE THE PRODUCT AS APPROVED.**

The product label contains specified information on dosages, conditions of use, withdrawal times, and other instructions for product use. The user should read the entire label and adhere strictly to its requirements and restrictions for use. Consultation with a pathologist or veterinarian is advisable.

**Best Management Practices**

- A diagnosis of the problem(s) should be obtained from a licensed pathologist or veterinarian before any treatment.
- Professional advice should be sought if there is any doubt as to when or how to use regulated products.
- Regulated products must be used only for those species and indications listed on the label, unless extra-label use is specifically prescribed by a licensed veterinarian.
- Product labels should be read and directions followed carefully.
- Proper dosage, amount, or concentration for the species, area, and/or specific condition should be used.
- A small portion of the afflicted population should be treated before treating the entire population to ensure efficacy and safety of treatment.
- Use the correct method and route of application or administration, whether by spraying aquatic vegetation, water treatment (ponds, tanks, or immersion), injection, or oral administration (medicated feed and some biologics).

- Withdrawal times should be calculated accurately.
- Treated populations or stocks should be clearly identified.
- Antibiotic drugs or medicated feed for disease prevention should not be used unless they are specifically approved for that use.
- Keep accurate records.
- Environmental impacts of discharging treated water should be mitigated.
- A producer quality assurance program or a HACCP program that provides guidelines for preventing tissue residue violations and for producing high-quality, wholesome products for consumer use should be implemented.
- Requirements concerning personal safety measures and proper procedures for farm workers and pesticide applicators that handle or apply regulated products should be followed.
- Economic consequences, both short- and long-term, of treatment should be considered before using a regulated product (Sometimes the best approach is to let the disease run its course).
- Nutritional requirements for particular species should be identified and proper feed should be used accordingly. Fresh, high quality feed should be used.
- Water quality should be monitored and maintained.

# **General Aquaculture Practices - Feed Management**

## **Management Considerations**

Feed should be of high quality, obtained from a reputable manufacturer, formulated for the species cultured, properly stored and consistently available.

## **Feed Management Issues**

- Feed sourcing
- Feeding schedule
- Feed storage

Effective management of feed begins with selecting the proper product for a particular species. Each species varies in its dietary requirement and companies produce different feed formulas accordingly. Most feed bags identify intended species, diet formulation, feed size, and date of manufacture. Specifically formulated feeds are available for only a modest number of fishes cultured; if no specific feed exists for species you are growing, use the nutritionally best diet available such as one with a high protein content. A diet in compliance with industry standards will improve overall fish health and eliminate undesirable water quality characteristics.

High quality feed is essential for good production and fish health. Inexpensive feed may not result in maximized profits as fish health and growth are negatively impacted. Feed should be fresh, of appropriate and consistent size, and with minimal “fines” or fragments of feed pellets. Inferior feed will cause water quality and fish health issues. It may be worthwhile to buy feed with other farms producing the same species and using the same company to get a lower price and consistent delivery.

Feeding rates should be based on percent body weight of fish. This percentage changes with the size of the fish (smaller fish require more feed as a percent of their body weight), species of fish and environmental factors, especially temperature. For most commercial species of fish, industry recommended feed conversion rates are available, from which feeding rates should be calculated. Fish should be sampled periodically to determine weights and feed rates adjusted accordingly. Fish should not be overfed. Over feeding results in poor water quality, adding stress to fish and the growing system and diminishing profitability.

Feed should be allotted over time, not at a single feeding to ensure that most of the allotted feed is consumed, eliminating waste accumulation. However, economic and time constraints may necessitate one feeding per day. Fish do not feed at the same rate everyday. Many factors can affect the feeding behavior of fish including temperature, pH, oxygen, and turbidity. Weather patterns and water levels can also affect fish feeding behavior. If feeding

behavior is affected for more than a few days or mortalities increase, feeding schedule should be altered and fish should be tested for suspected pathogens.

Daily records of feedings (time fed, amount fed, and feeding activity) should be kept. Documenting exact amounts fed will help track growth rates, allow for easier inventory of feed and promote efficiency of operation, hence profitability.

It is important to store feed in a cool, dry and pest-proof area. Primary containment (e.g. a small shed) easily accessible from the culture system is recommended. No gaps should be present in the storage floor, walls, or ceiling: mice can pass through holes the size of a dime. Feed bags should be grouped according to feed type and size. Feed should be stored on pallets or off the ground/concrete. Only one bag should be opened at a time. It is recommended that the feed in use be emptied into a secondary containment unit (plastic container) which seals shut. Wet feed, old feed or moldy feed should be discarded.

### **Best Management Practices**

- Feed should be purchased from a reputable manufacturer.
- Only fresh, high quality feed should be used.
- Nutritional requirements for particular species should be identified and proper feed should be used accordingly.
- Quality feed should be purchased in quantities that will be used during the manufacturer's recommended time period.
- Feed should be stored in a dry, cool and pest proof area. Feed should not be stored longer than manufacture's recommended time period. Weather damaged, moldy, contaminated or old feed should be discarded.
- Industry standard feeding rates, defined for specific species developmental stage should be used. Feeding rates should be adjusted according to fish behavior. Fish should not be overfed (no pellets should be left uneaten), nor should fish be underfed.
- Daily records of the amount of feed fed, time of feeding and behavior of fish when fed should be maintained.
- Fish should be routinely sampled to monitor growth rate and feed conversion. Feed size and amount should be adjusted for growth.

# **General Aquaculture Practices - Equipment Maintenance**

## **Management Considerations**

Properly operating an aquaculture system involves the use, maintenance, and repair of specialized equipment. Some systems (e.g. RAS) are technically more sophisticated than other systems and require more maintenance. All operators/employees should be familiar with equipment operations, maintenance, and repair.

## **Equipment Maintenance Issues**

- Selecting proper equipment
- Equipment inventory
- Back-up equipment
- Maintenance schedules

Proper selection of equipment is critical. Different company's products and warranties should be investigated. Operators should be familiar with specific equipment components and how they operate.

An easily accessible inventory of all equipment should be maintained. This file should contain manuals and warranty information. In an emergency it is important to know where key information is located. An inventory of back-up equipment and spare parts should also be established.

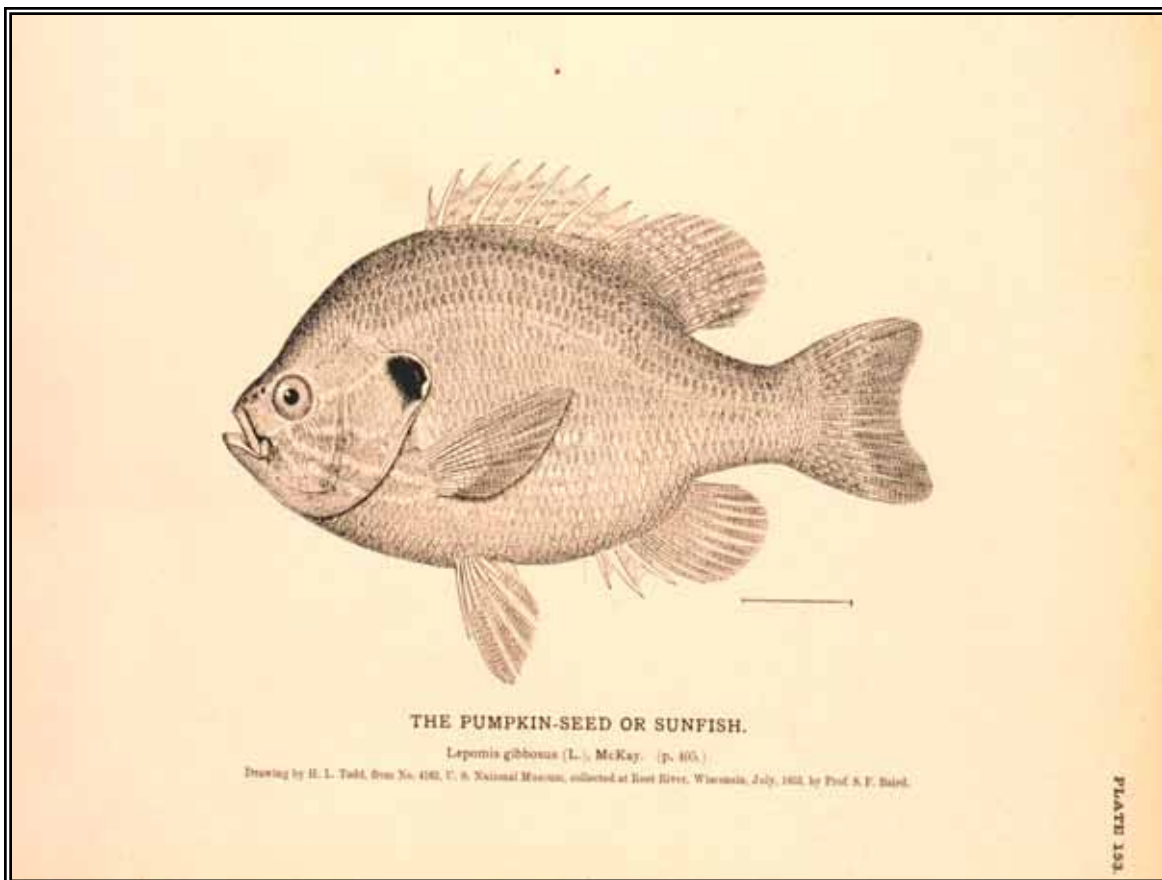
Operator's manual should be consulted for regular maintenance on specific equipment. A checklist for regular maintenance on all equipment should be established. Dates of service, repairs, and any changes to equipment should be recorded. These records will help troubleshoot problems during mechanical failures.

## **Best Management Practices**

- The best affordable equipment should be selected. Spare parts should be easily obtainable. Reputation and location of suppliers should be considered in terms of customer service and parts availability.
- Manuals for all equipment should be reviewed before installation. All manuals should be retained and stored for easy access.
- A logbook should be maintained to record equipment purchase, installation, maintenance and repair.



- Regular maintenance inspections should be performed on all equipment worn components should be replaced.
- Generators, back-ups for essential equipment, and spare parts should be kept in stock.
- Contingency plans should be drafted for possible equipment failures.
- All personnel should be knowledgeable of equipment operation and location of relevant materials should a disruption occurs.



# **General Aquaculture Practices - Biosecurity**

## **Management Considerations**

One of the greatest threats to an aquaculture facility is disease outbreak. A biosecurity plan should be implemented to prevent the introduction of disease agents. Biosecurity also guards against other invasive threats, including unwanted fish species, plants, invertebrates and chemical contaminants.

## **Biosecurity Issues**

- Fish Source/Health
- Water Source
- Personnel, visitor, and equipment sanitation
- Biosecurity Plan

All incoming fish should be obtained from reputable suppliers and accompanied by a health certificate verifying their disease-free status. Fish should be quarantined upon arrival and eggs should be sterilized in a biologically secure location upon arrival.

The water source of the facility should be checked for contamination and, where possible, the water source history investigated. Any surface water or runoff source should be checked for possible points of intrusion. Introduction of a wild fish species will increase the chance of exposing stock to diseases and elevate stress levels.

Sanitation points should be located in areas of heavy traffic around the facility. Upon entering buildings containing culture areas, footbaths should be positioned inside the doorways to disinfect boots. Hand sterilizers should be available and applied before working in any culture area or when moving between culture areas.

No equipment from off-site should be used at the facility. All equipment (nets, boots, scales, gloves, etc.) should be sterilized after use in the system. The date when dip baths, footbaths, and disinfecting sprays are changed should be recorded. It is beneficial to assign each production unit (e.g., pond, raceway, cage, RAS) separate equipment.

A meeting area should be designated where visitors sanitize footwear and hands before touring the facility. No visitors should place their hands in any culture tank or area of water collection at the facility. Vehicles from other aquaculture facilities should be restricted or disinfected. Gear, including boots from fishermen and other visitors of waterways, should be prohibited or disinfected.

All organisms not critical to fish culture, including pets, livestock and ornamental plants should be prohibited from culture areas.

All means of reducing stress and eliminating the introduction of disease should be developed in a biosecurity plan (see below). This plan should outline specific actions for certain activities and be mandatory for all employees to review.

The following model plan, adapted from the Utah Department of Agriculture ([http://www.ag.state.ut.us/animind/aq\\_biosecurity.pdf](http://www.ag.state.ut.us/animind/aq_biosecurity.pdf)), can be used to develop a specific biosecurity plan for a facility.

## **Aquaculture Biosecurity Plan**

### **Facility Grounds**

1. A sign is posted explaining the biosecurity plan, disease control efforts and the rules of your site.
2. Premises are maintained in a clean manner. Raceways, pools, screens and hatchery areas are cleaned daily.
3. The facility is fenced and gates are locked.
4. The water supply is restricted or fenced.
5. The water quality is tested and maintained.
6. The water supply is kept fish-free or double screened to prevent entry of exotics to the facility.
7. The feed storage area is secure and protected from pests and excessive heat.
8. Culture systems are covered with bird netting.
9. Dirt runs are covered with cement.
10. Pets and livestock are not allowed on the site. Ornamental plants are eliminated from buildings where fish or eggs are cultured.
11. A rodent control program is established.
12. Disinfecting footbaths and hand sanitizers are provided at key entry points.
13. Public access is controlled. The public and their vehicles are restricted to designated areas. Visitors are escorted through the facility.
14. Appropriate local, state and federal agencies (e.g. conservation commission, Department of Environmental Protection, Division of Fisheries and Wildlife) should be notified in cases of unusual occurrence such as high escape numbers, fish deaths or flooding. A list of response actions and appropriate contacts should be readily available.

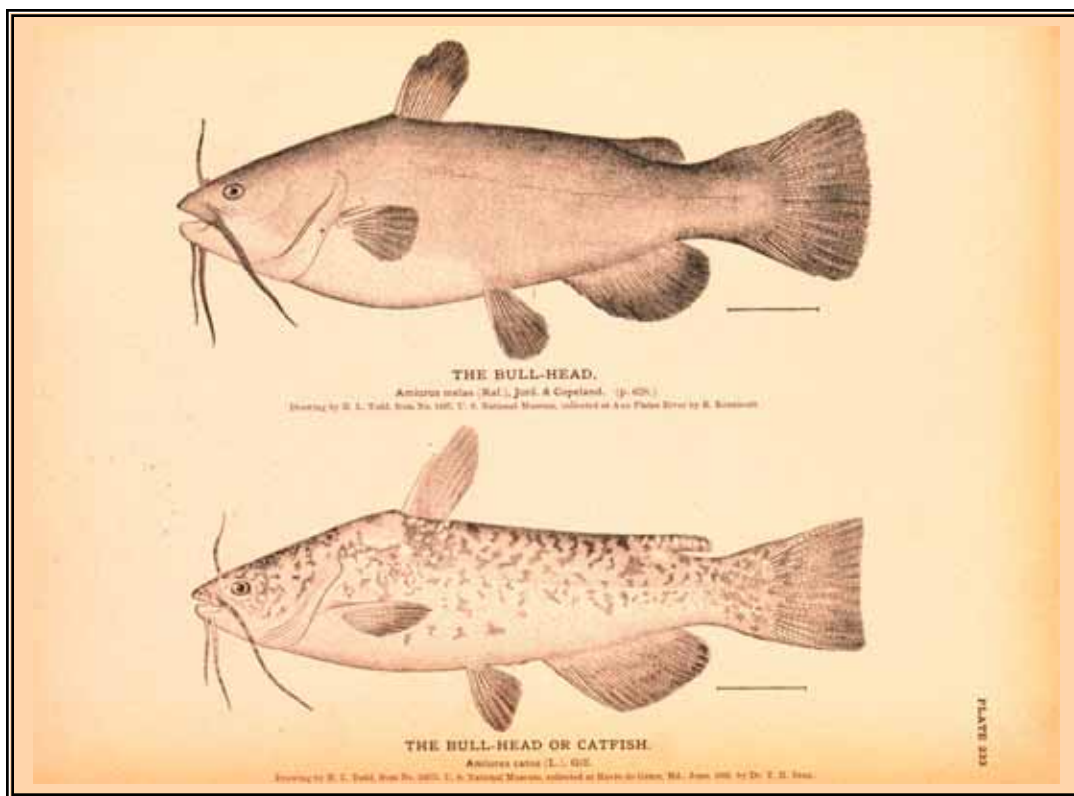
### **Management Practices**

1. Appropriately trained personnel are assigned to important duties.
2. Workers have clean outer garments.
3. Facilities are stocked at optimum levels.
4. Stressful conditions, such as overcrowding or poor water quality, are eliminated.
5. Fish are taken off feed one to two days prior to handling, grading, shipping, etc.
6. All incoming fish are properly inspected, certified, and quarantined.
7. When handling or feeding, youngest fish are attended first: diseased fish are attended last. In flow-through systems, start upstream, and work downstream.
8. All mortalities are removed and properly disposed daily, in accordance to local and state regulations. Records are maintained of daily mortality.
9. Appropriate vaccines are used where possible.
10. Double screens are placed at the end of every run, raceway or pond.
11. When possible, RASs, raceways and ponds are disinfected between each lot of fish. There are few legal disinfectants. Only appropriate products and labeled are to be used.
12. Quiescent zones and sediment settling areas are free of fish

13. Personal or farm vehicles are not driven to facilities known to be infected with fish pathogens. Any exposed vehicle is washed, with care taken to remove any mud or water from the facility.
14. Personnel avoid visiting facilities known to be infected with fish pathogens. No soil or water is transferred from these facilities.

### **Equipment**

1. No equipment from off-site is used on the premises.
2. Separate sets of equipment, such as waders, nets, etc, are used at each site.
3. Equipment is stored in a well maintained area, free of pests.
4. Equipment is cleaned daily or after each use.
5. Any vehicle exposed to a site containing prohibited pathogens is cleaned and sanitized before entering the premises.



# **General Aquaculture Practices - Transportation and Handling**

## **Management Considerations**

Fish may be transported from a supplier to the fish farm or from the farm to a customer. Transportation can be very stressful to fish and increased stress will amplify mortality. Reducing key stressors will increase survival during transport.

## **Transportation and Handling Issues**

Equipment selection

- Fish care prior to transporting
- Transfer from culture area to hauling tank
- Supplemental aeration and oxygenation
- Stocking densities

Proper equipment should be selected when handling and transporting fish. Hauling tanks are available in a wide range of sizes. Access to small, medium, and large volume tanks allows the grower to accomplish tasks of different requirements. Insulated units minimize temperature change during transit. The standard hauling ratio of one pound of fish to one gallon of water can be used as a guide, but other factors which will determine actual hauling densities. Fingerlings should be stocked at a lower ratio as the greater number of fish in the hauling tank consumes more oxygen. Larger fish will occupy more space limiting hauling amounts. Other factors affecting hauling densities include outdoor temperature, sun exposure, and length of trip.

Fish should not be fed for 3-4 feedings prior to a scheduled shipment. Fecal matter depletes water quality, creating unwanted stress for fish. Purging will reduce waste accumulation and oxygen demand in the hauling tank during transport.

Fish should be kept in water as much as possible when moved from culture area to hauling tank. Fish can be segregated for transport prior to shipping day, then moved to hauling tank in buckets with water.

Supplemental aeration or oxygenation is needed to transport live fish. Oxygen can be supplied by aerators, agitators, or oxygenation systems. When trucking high densities of fish, aeration is needed to remove CO<sub>2</sub> which creates carbonic acid, lowering pH. Transport tanks should be vented.

To minimize time in transport, deliveries should be direct: stops should only be made to check equipment and fish health. Transportation should be scheduled during times of cooler temperatures and reduced traffic.

## **Best Management Practices**

- Proper equipment should be used for specific transport needs.
- Hauling equipment should be cleaned, disinfected and rinsed before use.
- Grower should have access to different sized hauling tanks for different shipping volumes.
- Fish should not be fed for three to four feedings (1-2 days) before transport.
- Fish should be kept in water as much as possible during movement from culture area to the hauling tank.
- Proper aeration or oxygenation systems should be employed during transportation. Backup systems are desirable should a failure occur.
- Industry standard hauling densities should be adjusted for environmental factors, fish size and behavior.
- Transport water temperatures should be adjusted before transferring fish to minimize temperature related stress.

# **General Aquaculture Practices - Predator Management**

## **Management Consideration**

Predators cause fish losses directly and indirectly, by increasing stress on stocks resulting in mortality. Depending on the culture system, eliminating losses due to predators may be extremely difficult, but measures can be taken to reduce losses.

## **Predation Issues**

- Determining problem species
- Determining level of predation
- Selection of control methods
- Appropriate permits
- Implementation a predation management plan

Fish attract predators, especially in open and semi-closed systems. By concentrating prey, aquaculture facilities enhance this attractiveness. Certain species are particularly problematic at aquaculture facilities in the Commonwealth. Avian predators (heron, king fisher, osprey) feed on stocks primarily from late spring to fall. Mammalian predators (otter, mink, fisher cat, etc.) tend to be more prominent in the winter months.

Predation by birds is easier to recognize. Birds mainly prey in the daytime and tend to return to specific areas. Mammals are usually nocturnal and more elusive than birds; Often only their signs provide species identification. Signs of land predators (e.g. tracks, scat, and slides) are more evident in winter due to snow cover. If classification proves difficult, motion cameras can be set up around culture area for specific identification of predators. Assistance can be provided by USDA wildlife control specialists.

Some predator management options are determined by the type of culture system. Tanks, pools, and raceways can be covered with netting as a primary defense. Ponds tend to be larger in size and may require alternate methods such as fencing if larger than approximately 0.2 acre. RAS systems tend to be enclosed in Massachusetts, but predators will be attracted indoors if openings (doors, windows, loading zones, etc.) are not closed after use. Other management options include electric wire and visual and audio deterrents.

Birds and mammals are intelligent organism that often become habituated to deterrent devices. Different types of deterrents need to be employed in rotation. Maintaining a human or canine presence on the property often reduces predation. Regardless of the deterrent system selected, a seasonal plan should be implemented and modified from season to season to achieve maximum success.

Massachusetts General Law, Chapter 131, Section 37, gives property owners the right to use lawful means to destroy wildlife in the act of causing damage or threatening personal safety. The public may only address wildlife actually causing damage or posing immediate threats: wildlife cannot be killed as a preventive measure. A report must be filed following any killing of wildlife. The Migratory Bird Treaty Act authorizes the issuance of permits to control depredating birds such as herons and raptors if other methods have been found ineffective. For additional information on problem animal control, see [http://www.mass.gov/dfwele/dfw/dfw\\_pac.htm](http://www.mass.gov/dfwele/dfw/dfw_pac.htm) and Permits and Regulations, Chapter 6 in this manual.

### **Best Management Practices**

- Feed containers should be secure and kept out of reach of predators.
- Weed and brush should be reduced around culture areas.
- Where appropriate, trees should be removed to reduce nesting and perching sites for birds.
- Consult with federal, state and local officials concerning restrictions or required permits with regards to predator control or intervention.
- Problem predator species should be positively identified before corrective actions are taken.
- Deterrent systems should be established before predators establish a feeding routine.
- Deterrent systems should include a variety of devices employed at different locations and different times.
- Success of deterrent methods should be monitored and losses to predation should be recorded.
- Seasonal plans should be adjusted when necessary for continued success.
- If deterrent methods are ineffective, kill permits may be obtained from appropriate state and federal wildlife authorities.



# **Pond and Cage Culture \_\_\_\_\_ Chapter 3**

Pond aquaculture is the oldest and simplest type of aquaculture operation. Massachusetts has many farm ponds that could be converted into aquaculture ponds. Ponds may be used for pond culture (growing fish directly in ponds for harvest), pay-to-fish operations, or cage culture (growing fish in small manageable cages).

Fish may be grown in naturally formed ponds, or ponds may be constructed by excavation or impoundment, although sites suitable for impoundment are not common. Water sources for ponds may originate from ground springs, bored wells, streams or runoff. Stocking densities in ponds vary with species, pond size and depth, water source, aeration and the needs/abilities of the producer.

While many ponds can be used for aquaculture, water quality is generally enhanced when ponds are larger, deeper (8 feet or more) and there is little (>2 ft) or water fluctuation. The pond should not be subject to run-off from agriculture and livestock should not have access to the pond. A vegetated watershed will have less siltation issues.

Pond culture is generally used to grow baitfish or game fish species such as trout, largemouth bass, bluegill sunfish or bullhead, and ornamental species. The system may consist of a single pond or several ponds in series connected by channels to regulate water flows. Pond size typically varies from 1/16 acre up to 5 acres. Pond shape and depth varies, and affects potential use of the pond. If constructed specifically for pond culture, an excavated pond should be rectangular in shape.

Many beginners in aquaculture start with cage culture because of its low start up cost and technology requirements. Cage culture is generally used to culture game, ornamental or food fish. Cages vary in size and shape depending upon pond size, design and preferences of the culturist.

While general principles of pond management apply to most situations, every pond is unique and the expectations of producers vary widely. Specific management practices may not be appropriate in every situation.

Not all ponds are suited for aquaculture and different aquaculture projects may have specific water temperature and quality requirements. An aquaculture specialist should be consulted before initiating a commercial endeavor.

## Pond and Cage Culture - System Design

*Appropriate permits should be obtained from local and state agencies before digging new ponds or dredging existing ponds. See Chapter 6 in this manual.*

### Management Considerations

All ponds are not suited for aquaculture. Before using an existing pond for aquaculture, the following parameters should be evaluated: water quality, pond dimensions (including length, width and depth), water source, substrate, other aquatic life and accessibility.

New ponds should be constructed with consideration of specific requirements of the intended fish species. Information on fish physical requirements can be found in references at the end of this publication or through search engines on the internet. A wide variety of technical assistance materials can be obtained through local USDA NRCS offices. See References, Chapter 8 of this manual.

### Principal Design Elements

**Water Supply:** Ponds may be supplied with water from different sources: springs, streams or other surface water, and wells. Filling rates are variable, but water flow should be sufficient to fill the pond in less than one week. Spring-fed ponds are generally cold or cool water ponds. Stream or surface fed ponds are generally cool or warm during spring and summer, but cooler in fall and winter. Ponds fed from wells vary in temperature depending on the depths of wells and frequency of water addition. Generally, ponds are static, thermally dynamic waters that stratify and destratify diurnally. Surface waters warm and remain oxygenated, while subsurface waters are cooler and may become oxygen diminished, on a daily basis. Fluctuations in dissolved oxygen and water quality intensify as summer progresses and fish biomass and feeding rates increase. In Massachusetts, most bedrock contains little limestone and runoff/ground water may be acidic, as such alkalinity is typically low and should be corrected through the addition of crushed limestone or sodium bicarbonate. Ponds constructed specifically or intentionally for aquaculture should include drains so water quality and quantity can be managed.

**Water Outlet/ Discharge:** Pond outlets should be screened to prevent fish from escaping and unwanted species from entering. Largemouth bass are notoriously adept at escaping through unscreened portals. Where possible, ponds should be equipped with adjustable outlet pipes or dam boards to control water levels.

**Pond Shape & Depth:** Pond shape and depth varies with its intended use. In general, ponds should be rectangular in shape to facilitate seining. Bottoms should be sloped (1-3% gradient) to facilitate draining. Internal slopes should be 3:1 to minimize shallow water conducive to plant growth, yet sufficiently gradual sloping to promote easy access and bank

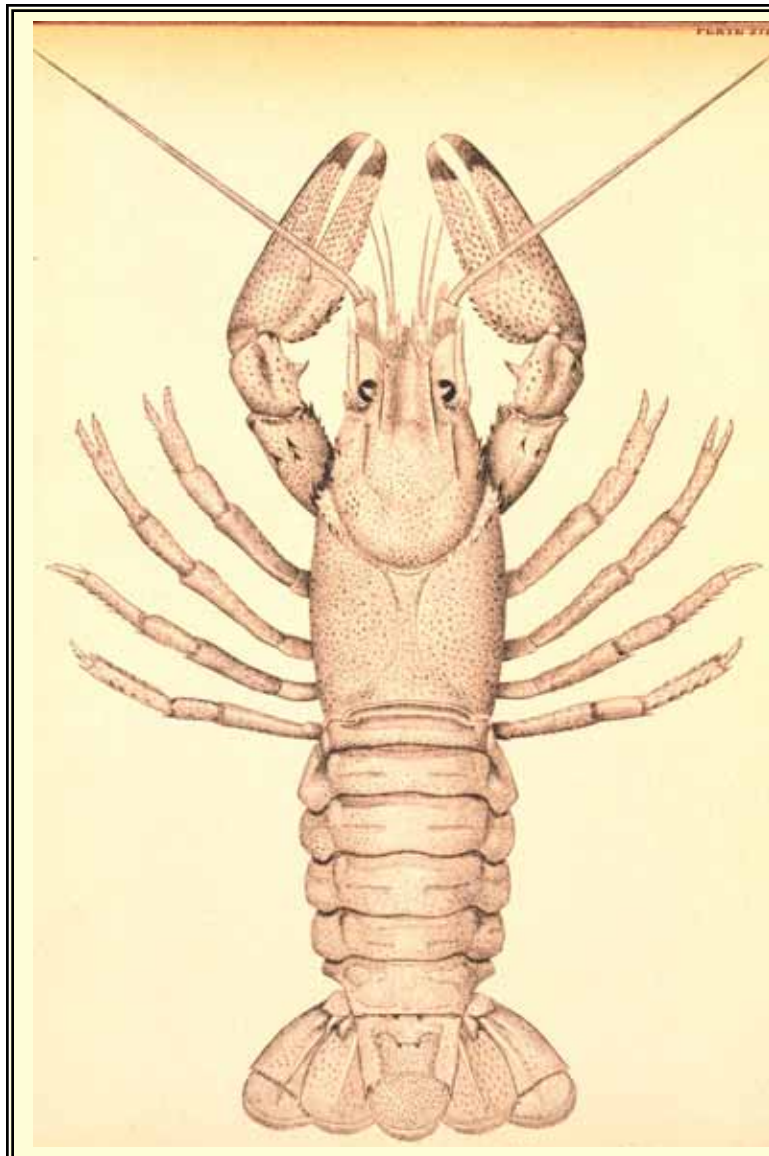
integrity. Adequate free-board, 1 foot, should be included to facilitate access and water management. Newly construction ponds should be designed specifically for desired species. If earth is suspect or vulnerable to seepage, ponds may be lined with plastic liners or clay bottoms to eliminate water percolation. Existing ponds should be stocked with fish appropriate for the pond's capabilities, perhaps employing cage culture.

**Aeration / Pumping:** Intensive pond culture may require supplemental or continuous aeration supplied by surface or submerged aerators, pumping or movement of large amounts of water or a combination of methods. Solar powered aerators may be employed in remote sites. When relying on electrical powered aeration, a back up generator should be available.

### **Best Management Practices**

- All ponds are not suitable for aquaculture. Before existing ponds are used for aquaculture, a survey should be conducted to verify the pond is suitable for raising fish.
- Watershed issues should be considered when building new ponds. Ponds should be located to ensure a proper ratio of watershed to pond area. Ponds should not be sited in flood-prone areas, salt marshes or other ecologically sensitive areas. Construction of ponds should not alter natural water flows needed to maintain surrounding habitats. Watershed ponds should not be located where embankment failure can damage public or private structures or facilities.
- Ponds should not be subject to agricultural run-off or accessible to livestock.
- Ideally, soil should have a mix of sand, silt and clay suitable to resist erosion and seepage. Plastic liners or clay may be used.
- The use of constructed wetlands or a settling basin to reduce effluent nutrients should be considered.
- Ponds used year-round should be at least eight feet deep.
- Constructed pond bottoms should be smooth and with adequate slope to allow complete drainage, to minimize growth of aquatic vegetation and to facilitate harvest.
- Recommended slopes for ponds: outside, 2:1; inside 3:1. Steeper inside slopes will discourage predation by wading birds, but complicate harvest.

- A drain system should be installed to permit the pond to be fully drained. The drain should be designed to prevent accidental draining. Anti-seep collars should be installed around the drain pipe.
- Pond inlets and outlets should be screened to prevent fish escape and impede entry by predators and competing species
- If relying on electrical power for aeration or other critical functions, a backup generator should be available.
- Construction of field borders and filter strips should be considered to improve water quality.



# **Pond and Cage Culture - Waste Management**

## **Management Considerations**

Ponds used for intensive fish culture should be drained and dredged every year, preferably in the late fall after the harvest season. Less intensive pond and cage culture should be dredged once every three to five years.

## **Waste Management Issues**

- Reduction of waste inputs
- Removal of waste from pond
- Proper disposal of waste after removal

Reduction of waste improves water quality, increases productivity, lowers production cost, and reduces environmental impacts.

Ponds used for intensive pond and cage culture (on the order of 5,000 or more pounds of fish per acre per year) will require draining and dredging. Less intensive production will require periodic maintenance. The frequency and methods of waste removal will depend upon species, stocking density, production volume and design of the pond system. Properly maintained ponds will reduce disease, increase productivity, and lower environmental impact.

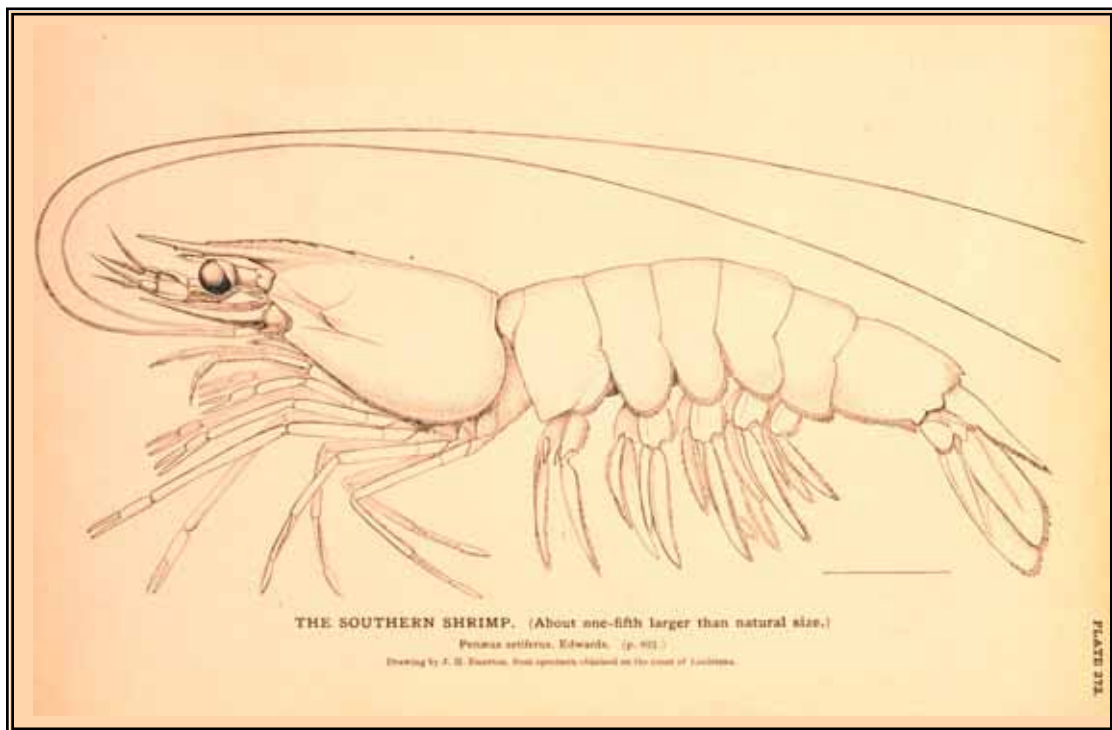
Waste removed from aquaculture ponds, consists of decomposed fish, fecal matter, uneaten feed and other pond debris, and is rich in nitrites and ammonia. This organic material can be used for agricultural crops, in compost facilities or as a topsoil additive. If these options are not available, waste may be sent to a landfill or waste treatment facility for disposal.

In ponds, draining and management of discharged water is of sporadic importance, which can be handled by draining from the pond surface and the use of detention ponds. More critical is management of biological oxygen demand (BOD) and chemical oxygen demand (COD) as well as nitrogenous wastes generated in the pond, which may become stressful or toxic to fish. This is particularly true for cage culture, where enclosed fish are unable to relocate from areas where water quality has been locally compromised to locations of better water quality.

## **Best Management Practices**

- Proper feed management should be employed to reduce the generation of waste.
- Ponds should be sited away from or shielded from leaf and vegetation debris. Unwanted debris increases organic material and oxygen demand in ponds and reduces water quality.

- In ponds used for cage culture, cages should be rotated periodically throughout the pond to preclude depositing excessive wastes (largely feces) below the cage. that results in localized degraded water quality.
- If ponds are drained or dredged, this activity should be initiated in the fall, after harvest.
- In general, fish should be over-wintered only in ponds that have a depth of eight feet or more. Allowing ponds to be lightly stocked through the winter months will improve survival. It is recommended that ponds used to over-winter fish be aerated to prevent ice from forming and the accumulation of light-impeding snow.



# **Pond and Cage Culture -Water Management**

## **Management Considerations**

Good water quality is the foundation of fish health and successful aquaculture. Success in aquaculture depends on the producer's ability to maintain suitable levels of dissolved oxygen and other water quality parameters. In some ponds, sufficient water flow can be maintained throughout the pond system to improve water quality and reduce accumulation of nitrogen and phosphorous, thereby limiting algae blooms. However, in most cases, ponds fill with water and are managed as closed systems with only sporadic additions of water (e.g., rain).

## **Water management Issues**

- Pond water quality
- Pond water flow
- Water discharge

Pond water quality criteria differ with the species raised, pond size, geographical location and initial water source. Water quality parameters that should be monitored include: ammonia, nitrite, alkalinity, pH, dissolved oxygen, turbidity, temperature and total hardness. The frequency of testing depends on intensity of pond use. Ponds should also be checked for contaminants before construction and then periodically, depending on the potential for contamination.

Pond water flow or turnover rate depends on stocking density, pond size and species cultured. Control of water flow can be limited depending on the primary water source. However, most ponds are static waters, receiving little or no addition of water. Pond water can originate from, springs, streams or brooks, surface water runoff, drilled wells or a combination of these sources. Altering a source of water by drilling new wells or by creating channels of surface water is subject to state and local regulation: the appropriate agencies should be consulted. See Permits and Regulations, Chapter 6 in this manual.

Water discharge should be monitored. Water flow and discharge from ponds is a minor problem to the environment as overflow water is relatively high quality. Water from the bottom or with considerable suspended material, disrupted by seining, has a much greater nutrient load.

## **Best Management Practices**

- An initial test of the water source should be conducted to determine it is free of contaminants, including parasites, pathogens, disease or any other environmental impurities. If problems exist, suitable remedial actions must be initiated to correct the situation.

- Water quality parameters (ammonia, nitrite, alkalinity, pH, dissolved oxygen, turbidity, temperature and total hardness) should be routinely tested (see References for monitoring frequency and techniques). Records of water testing results should be maintained on standardized data sheets. In pond culture, the dissolved oxygen level is the most critical: this should be monitored. Emergency or supplemental aeration should be turned-on if oxygen values are anticipated to fall below 3 mg/L.
- Water inflow and discharge volume should be measured and recorded throughout the year to determine the amount of water used annually.
- Water flow should be regulated to meet industry standard water quality requirements for species cultured. In general, water flow reduces nutrient load in the pond, increasing production capacity. Increased water flow can reduce water temperature in the summer and reduce ice formation in the winter.
- Water discharged should be monitored to prevent impacts on the surrounding environment.
- If ponds are small and water exchange minimal sodium bicarbonate can be added to help achieve neutral pH. Lime may be added to acidic soils in the watershed to increase pH.
- Use of pesticides should be avoided in the watershed area. Where pesticides are used, state regulations and label instructions must be conscientiously followed.
- Aeration and circulation systems can be installed to increase production capacity, reduce mortality, decrease stratification and prevent winter-kill.



## **Pond and Cage Culture – Cage Culture**

### **Management Considerations**

Cage culture provides an inexpensive means to develop aquaculture skills. Many existing ponds can be used and construction costs are minimal. With cage culture, monitoring fish health and growth, protection from predators and harvest procedures are simplified. However, production rates are lower than in direct pond culture and under high stocking rates, water quality problems (especially dissolved oxygen), and disease outbreaks can develop.

Management practices for pond culture also apply to cage culture, but cage culture requires additional attention. Because fish cannot adjust their environment by moving to pond locations with more favorable environmental conditions, the grower must locate cages in optimal locations, regularly monitor their condition and make appropriate adjustments.

### **Cage Culture Issues**

- Cage construction
- Site selection
- Cage placement

Cages can be constructed of a variety of materials that are non-toxic (zinc and copper are toxic) and rustproof. Durability and resistance to UV deterioration should be considered. Cages should be a minimum of 1 cubic meter, and include a cover, to prevent escape, predation and stress from sunlight. Mesh should allow maximum water circulation and a feeding ring with a smaller mesh size should be included to prevent floating feed from escaping.

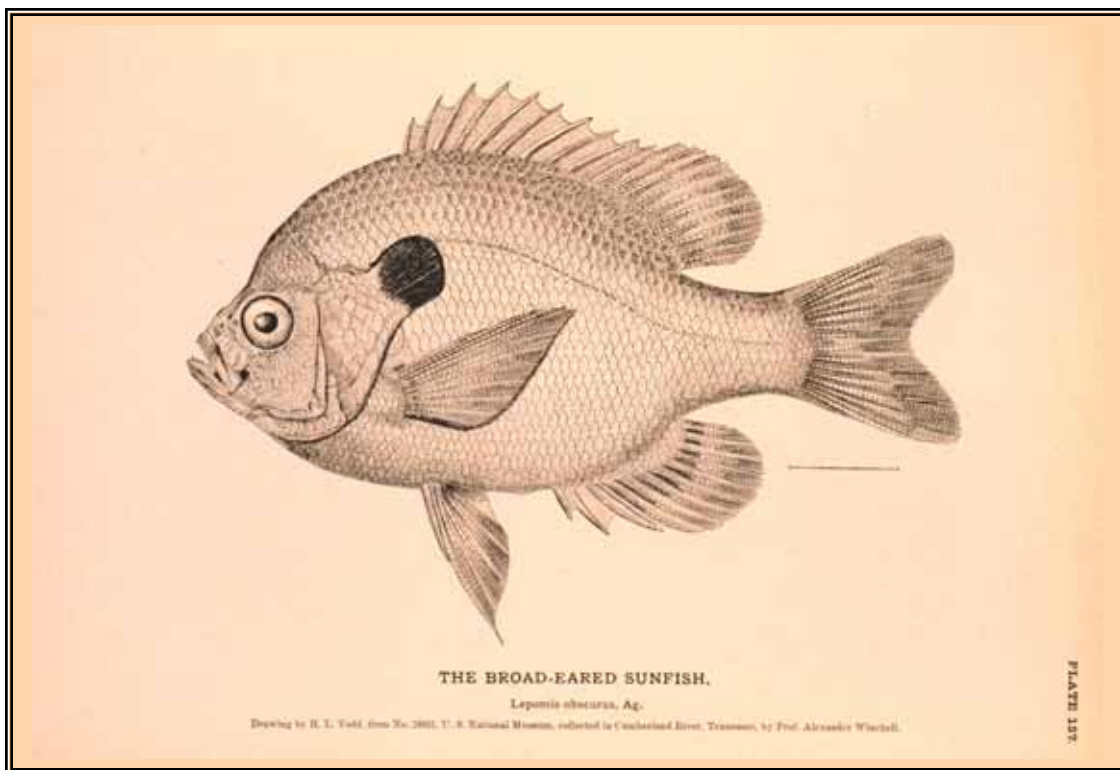
Cage placement is critical to successful cage culture. Fish wastes and excess feed must fall through and away from the cage, thus a minimum of two feet of clearance should be provided to prevent wastes from accumulating below the cage. Water should circulate freely through and around the cage.

Because fish cannot forage to supplement their diets, the use of high quality, nutritionally complete feed is essential. Floating feeds should be used to prevent loss through the bottom of the cage.

### **Best Management Practices**

- Cages should be constructed of durable non-toxic materials. Mesh size should be at least ½ inch and each cage should have a cover and a feeding ring. All openings should be laced closed.

- Cages should be placed in areas of easy access to encourage regular feeding and monitoring.
- Cages should be located where water circulates freely. Structures and vegetation should be avoided. Areas with wind action are preferred.
- Cages should be spaced at least three feet apart.
- Activities such as swimming, fishing or boating should be avoided near the cage.



# Flow Through System \_\_\_\_\_ Chapter 4

Aquaculture systems which rear fish in pools, tanks or raceways, where water continually flows in and out of the culture system are called Flow-Through Systems (FTS). A system can be supplied with pumped-in ground water, surface water (stream or spring), or gravity fed artesian well. The availability of water will determine the system design.

FTS possess distinct advantages and disadvantages. The water source of a FTS usually supplies enough dissolved oxygen to initially sustain stocks and dissolved oxygen (DO) is replenished passively through splash aeration. However, water is commonly used four or more times and, after multiple uses, ammonia and metabolites accumulate are a limiting factor and the water is discharged. There is minimal fluctuation of water quality (temperature, etc.) in a FTS and the consistent water quality reduces fish stress and facilitates management. However, fish cultured in FTS are susceptible to pollution and disease exposure from external water sources (springs and streams). High stocking densities provide for rapid disease transmission. Site properties, principally water temperature, will most often dictate which species can be cultured.

## Flow Through System (FTS) - System Design

*Appropriate permits should be obtained from local and state agencies before developing or modifying any system. See Chapter 6 of this manual. Permitting of FTS is particularly challenging as an existing, flowing water source is commonly tapped. Additionally, discharge from FTS must be treated before return to public waters. Permits to take water, pollute it and return it are difficult to secure. High quality water is increasingly viewed as a resource to preserve.*

### Management Considerations

Production goals should be determined prior to developing a system design. A tentative site should first be identified and the likelihood of securing permits ascertained. Site selection is one of the most important steps in FTS. When possible, natural landscape features should be utilized to minimize land clearing, leveling and other construction costs.

The same principal design elements should be employed for constructed pools, steel tanks and raceways except that earthen pools are challenging to manage.

In establishing a new FTS facility where water is to be supplied from groundwater, test wells should be dug to establish quality and quantity of water available; information can be obtained from drilling companies on existing aquifers.

## **Principal Design Elements**

**Water Inlet:** Spray bar or pipe supplying water to a particular culture system. Valves or spillways can be attached to adjust flow rates to a particular tank or raceway depending on particular stocking density. Running water through a packed column will decrease nitrogen levels and increase oxygen.

**Sump or Waste Collection:** Area in pool or raceway designated for the collection of waste products generated in fish culture. This area contains a drain. Waste will be flushed from the system by removing a stand-pipe or plug. A raceway without a waste drain can be vacuumed using a small pump and basic pool cleaning supplies to remove waste products. Waste is collected into a primary settling pond for collection of larger waste and then passed through a secondary polishing pond to further filter water before discharge.

**Culture Tank:** The area where fish are grown. Size, shape, and design of the tank are dependent on species, available water supply, and desired production rate.

**Water Outlet:** The point where water leaves the culture system. This should be located adjacent to waste collection area. Stand-pipes and dam boards should be used to regulate water flow. Outlets should be screened to limit escape of cultured species. Surface water is discharged, while subsurface water containing suspended wastes are retained to facilitate settling of solids.

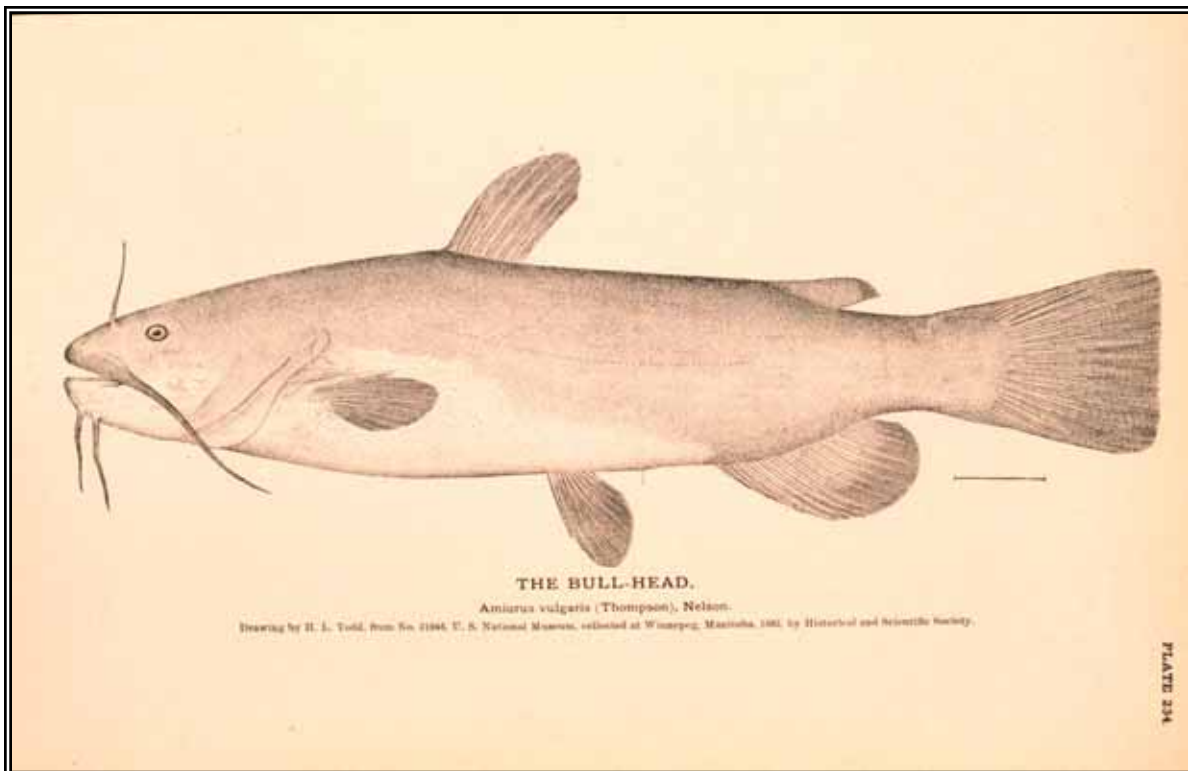
**Waste Discharge:** Drain or stand-pipe which can be removed easily allowing waste and solids to be discharged from system or to an area where solid wastes are allowed to accumulate.

**Covers:** The culture area should be covered with netting or translucent plastic to deter predation and prevent unwanted leaf matter and other debris from entering the system.

## **Best Management Practices**

- Appropriate local organizations and state agencies should be consulted before beginning construction on a facility.
- System should be designed based on site features and limitations, production goals, water source and time available for operation and maintenance.
- Design should provide for adjustment of water flow rates into culture tanks.
- Appropriate means of waste collection and discharge should be planned and integrated into the system.

- Culture area should be enclosed to deter predators and unwanted debris from entering system.
- System should be designed to facilitate passive re-aeration and concentration of solids for removal.



# **Flow Through System (FTS) - Waste Management**

## **Management Considerations**

Proper collection and disposal of waste is a key element for the proper operation of a FTS. Accumulation of waste and uneaten feed will adversely affect water quality, fish health, and system drainage.

## **Waste Management Issues**

- Proper feed management
- Primary collection of waste in culture area
- Disposal of waste to primary and secondary settling ponds

A key aspect to managing waste accumulation is ensuring appropriate inputs to the system. Feeding proper amounts of quality feed and observing fish feeding behavior diminish or eliminate accumulation of uneaten feed, which debase water quality. Less feces is produced when feed conversion is high.

Waste should accumulate away from cultured fish and be removed from the system daily. Daily monitoring and elimination of waste will help to ensure good water quality, clear drains and fish health.

Waste should be discharged from culture system into settling ponds in accordance to state and federal regulations. Solids settled in the ponds should be filtered and digested before water is discharged into a watershed.

## **Best Management Practices**

- Proper feed management should be employed to reduce generation of waste. Fresh, high quality feed should be used.
- All waste outlets should be screened to limit escape or invasion by exotic fish.
- Properly designed settling ponds should be established in accordance with state and federal regulations.
- Waste products must be effectively collected and removed.
- Sumps/waste collection areas should be drained daily in culture tanks to remove settled solids.

# **Flow Through System (FTS) - Water Management**

## **Management Considerations**

A FTS can be supplied with water from artesian wells, pumped groundwater, or surface water. Source water should be tested and evaluated against specific fish species requirements. Use of water must comply with local, state, and federal water withdrawal and discharge regulations.

## **Water Management Issues**

- Water quality of source
- Flow rates into system
- Water withdrawal and discharge

Preferred water quality characteristics are dependent upon the species cultured. An initial test should establish pH, dissolved oxygen content, and temperature of the water source. Contaminants should be investigated including heavy metals, organics and problematic ions (e.g., ferrous) and gases (e.g., H<sub>2</sub>S, NH<sub>3</sub>)

Groundwater offers an abundant water source with the capability of increasing flow rates through the use of pumps. This source often does not contain adequate dissolved oxygen; supplemental aeration might be required based on stocking densities and initial test results. Step-down section raceways passively improve oxygen levels. Oxygen levels can also be increased, and CO<sub>2</sub> and nitrogen levels reduced with spray bars or packed columns.

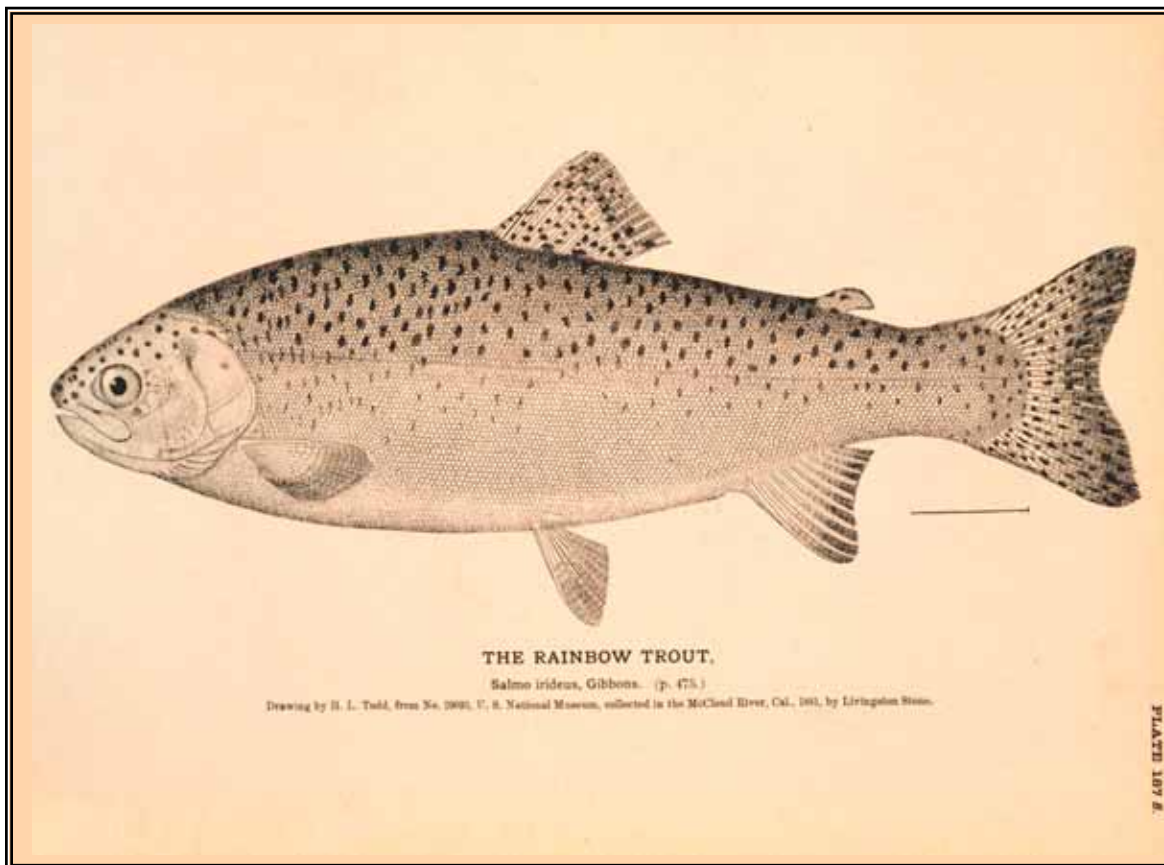
Artesian wells utilize gravity to move water through a culture system. They will generally show minimal fluctuation in water quality parameters which facilitates management, reduces stress, and improves overall health. Production can be limited to the available flow rate from a particular aquifer.

Stream fed sources offer a potentially inexpensive supply of water for an FTS. Associated expenses such as test wells, drilling, etc. are eliminated, but certain disadvantages emerge. Open surface water has greater variability in temperature and water quality, especially during snow melt. Supplying a system with surface water also increases the chance of exposing cultured fish to disease and contaminant. Inlets should be screened and monitored for unwanted debris, other fish species, and predators that may enter the system.

## **Best Management Practices**

- An initial test of the water source should be conducted to determine it is free of contaminants, including parasites, pathogens, disease or any other environmental impurities.

- Water flow should be regulated to meet industry standard water quality requirements for species cultured.
- Water withdrawal and discharge should be monitored in compliance with local, state, and federal regulations.





# **Recirculating Aquaculture System \_Chapter 5**

Recirculating aquaculture systems (RASs) permit farmers to rear fish in an indoor facility and locations where water quality or quantity would otherwise preclude commercial culture, permitting higher stocking densities and more complete environmental control. An outside water source is necessary to replace water lost to evaporation and waste removal. Unlike flow-through systems, RASs require filtration to remove particulate matter, nitrogen compounds, and other solid and dissolved waste.

RASs are the most effective way to culture large quantities of fish in limited space. Unlike other systems, RASs may be manipulated to manage temperature, water quality, and disease. This is especially advantageous in the northeast where temperature fluctuates throughout the year and the growing season is limited to a few months annually. In RASs, fish growth can be maintained at an optimal rate year round and due to its flexibility, growers can rear cold water, warm water or ornamental species.

RASs are more water efficient in terms of use of water per unit of production than other systems, losing 5% or less of the culture system water volume. Lower water use also results in reduced water discharge requirements. Collection of solids in RASs allows for higher stocking densities. In RASs, 1/2 lb of fish or more can be grown in one gallon of water, which is eight times more efficient than pond culture. However, increased production comes with increased management and production costs. RASs are complex systems that require considerable knowledge, commitment and resources to operate profitably.

## **Recirculating Aquaculture System (RAS) – System Design**

*Appropriate permits should be obtained from local and state agencies before developing or modifying any system. See Permits and Regulations, Chapter 6, in this manual.*

### **Management Considerations**

Because less space and land is required for RASs than other aquaculture systems, producers have greater control and can produce more fish in less area. System size, species cultured, economical feasibility and available land will determine system design. Growers should research markets and system designs meticulously before committing to construction.

System components include culture tanks, particle filter (usually a screened drum filter) or settling tank, bio-filter with chosen media (e.g. plastic, beads, or sand), heating or cooling systems, pumps (including water circulation pump and sump pump), aeration/oxygenation supply, appropriate lighting, CO<sub>2</sub> stripper, waste sump and disinfection system (e.g. UV or ozone, though ozone is not commonly used in the U.S.).

Primary design considerations are water supply, culture tanks, filtration and waste discharge.

### **Water Supply**

Water can be obtained from groundwater or municipal sources. Water from municipal systems will have greater costs and may require additional permits. All water sources should be investigated for possible contamination.

### **Culture Tanks**

The size of the system, desired production goals and the cultured species determine the size and shape of culture tanks. Any size or shape tank can be used but certain species may grow more efficiently in specific tank designs. Generally, cylindrical tanks are preferable to other shapes as they yield more uniform water quality and lend themselves to more efficient aeration/oxygenation and waste removal than other geometric shapes.

### **Filtration**

Different types of waste are collected through different methods. Particulate matter, composed largely of feces and uneaten food particles, is removed through such means as settling tanks, mechanical (drum) filters or sand filters. Metabolic nitrogenous wastes (ammonia and nitrite) are converted to non-toxic nitrate by bacteria contained within the biofilter. Suspended solids are removed by bead filters, foam fractionation or other flocculant-generating method. Dissolved solids are addressed through foam fractionation or ozonation.

### **Waste Discharge**

In some cases RASs may be allowed to discharge into municipal waste systems. This option may be cost prohibitive in most cases.

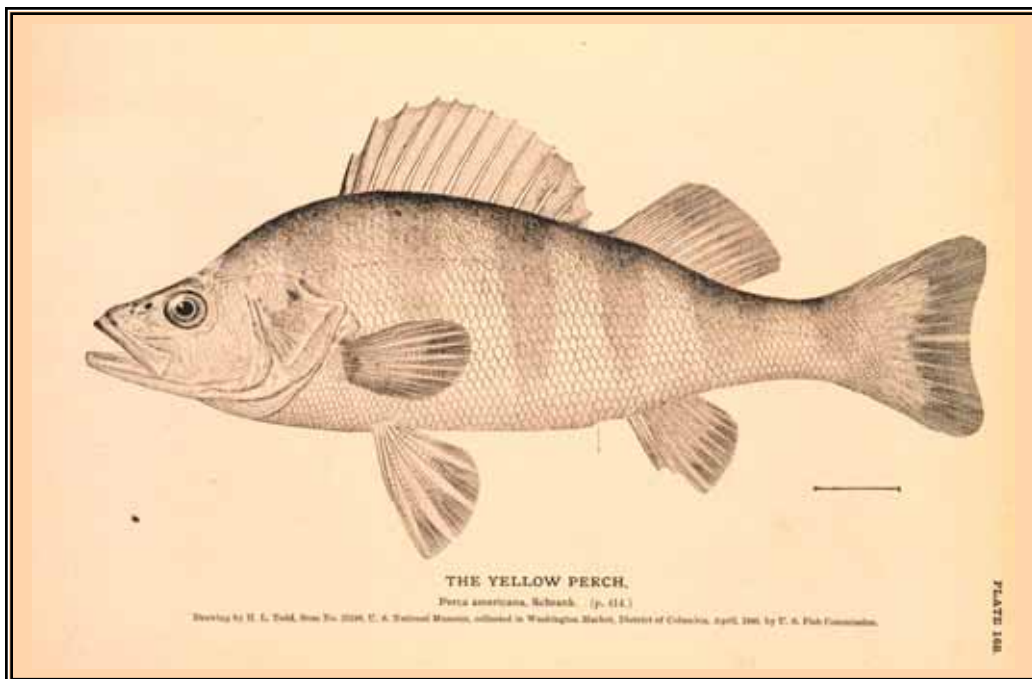
One method of waste treatment for a RAS is the use of ponds or manure collection tanks. Solids collected can be applied to land as an agricultural by-product. Treated waste water should be discharged or reused in the system.

Constructed Wetlands (CWL) can be used to digest waste from a RAS. Solids are collected in a lined bed where wetland plants are cultivated to digest solids and water is passed to a secondary polishing bed to further filter the water. The size of a CWL will vary depending upon the waste load.

### **Best Management Practices**

- Full time maintenance with levels of backup is required for a RAS.
- Alarm systems should be installed for critical factors at appropriate locations such as pump pressure, water flow, temperature, dissolved oxygen, and water level.

- Back-up generators and/or oxygen should be kept available to prevent loss in case of power failure.
- Lighting should be provided when fish are raised species indoors.
- UV or ozone filtration is beneficial in some system designs.
- CO<sub>2</sub> stripping may be required in a RAS due to high amounts fish waste and higher stocking densities ( $\geq 0.5$  lbs/gal).



# **Recirculating Aquaculture System (RAS) - Waste Management**

## **Management Considerations**

Waste management in RASs should be monitored in three parts: reducing waste in the culture system, collection of solid waste outside the culture system, and treatment of discharge water.

## **Waste Management Issues**

- Feeding Rates
- Solids management
- Metabolite management
- Collection/ discharge of waste

The use of high quality feed is essential. Industry feed rates should be followed for a particular species. Proper solids removal and maintenance of biological filters system will help to eliminate undesirable organics from the culture system. Flushing or backwashing of the biological filter may be required; frequency of flushes will depend on feeding rate and filter design.

Solids removed from RASs should be collected and disposed appropriately. Disposal methods are regulated by local, state and federal authorities. Wastes can sometimes be discharged into municipal waste systems, but this is often expensive. Solids can be applied as a soil amendment on local farms or used in composting operations. Waste water can be reused in the system after proper treatment or discharged.

## **Best Management Practices**

- Proper feed management should be employed to reduce generation of waste.
- Filtration systems (solids removal and biological filter) should be maintained and monitored on a regular basis.
- Flow from the biofilter to the tanks should be adequate to maintain industry standard water quality parameters for species cultured.
- Solids should be collected regularly and properly discharged.

# **Recirculating Aquaculture System (RAS) - Water Management**

## **Management Considerations**

A RAS recycles 90-99% of its water, thus, compared to FTS or pond culture very little “make-up” water is needed. However, water lost to evaporation and solids removal must be replaced. During nitrification, ammonia is released and CO<sub>2</sub> is lost from the system, diminishing buffering capacity of the water, leading to lower pH. Thus the grower must monitor and manage water quality by the use of buffers and other additives.

## **Water Management Issues**

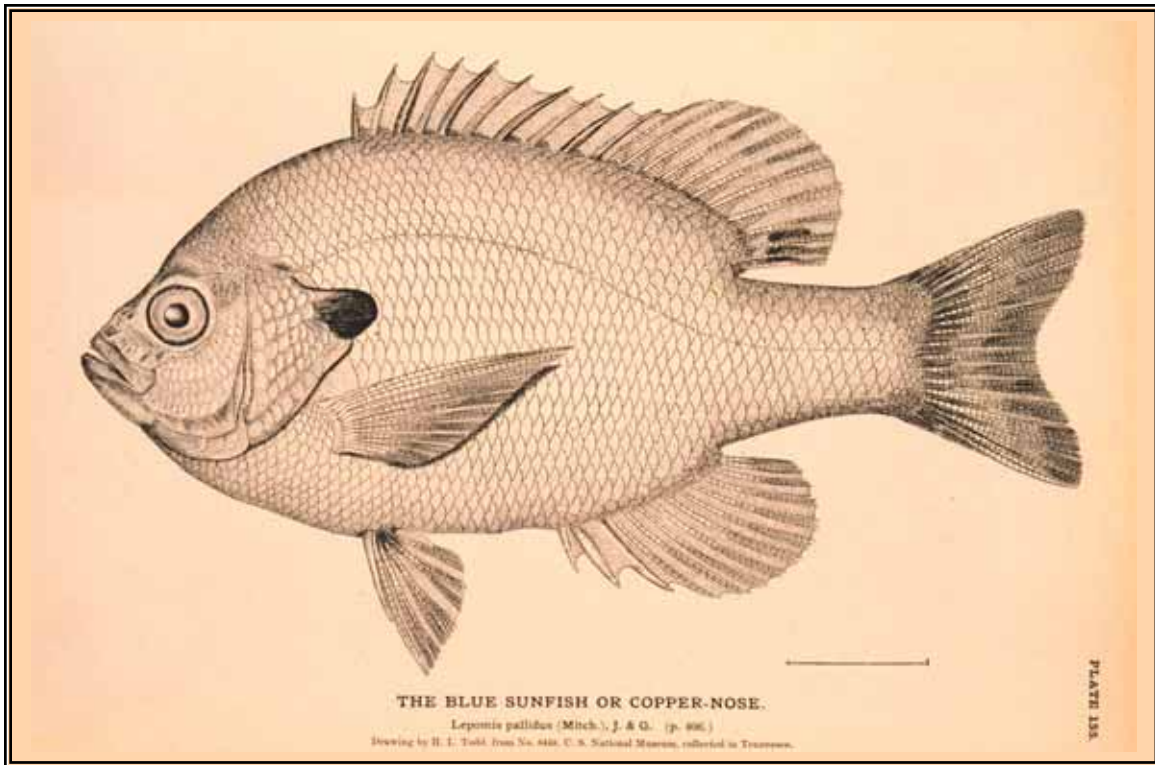
- Species selection
- Water quality testing
- Alarm systems

Maintenance of water quality is essential: the same water is used continuously in the system. Water quality in RASs primarily depends on the quality of recirculated water and the efficacy of water treatment systems. Water chemistry can change on an hourly basis as fish feed, metabolize and excrete: a number of water quality parameters should be monitored daily or more frequently. These parameters include; ammonia, nitrite, nitrate, alkalinity, pH, dissolved oxygen, turbidity and temperature. Suitable water quality parameters will depend on the fish species cultured.

An alarm system should be set up to monitor and signal when temperature, dissolved oxygen (DO) and pH are outside desired ranges. This allows for constant monitoring of critical water parameters crucial to fish health. Optimally, corrective measures should be initiated immediately when a critical parameter exceeds the desired range.

## **Best Management Practices**

- An initial test of the water source should be conducted to determine it is free of contaminants, including parasites, pathogens, disease or any other environmental impurities.
- Species reared should possess high tolerance to water quality fluctuations and the ability to grow rapidly in high stocking densities.
- Water quality should be monitored daily for ammonia, nitrite, nitrate, alkalinity, pH, dissolved oxygen, turbidity, temperature, using industry standards. Water quality data should be recorded daily.
- Computer monitoring of basic water quality parameters should be employed in a RAS. Alarm limits should be set just inside desired levels to insure that notification and response before an emergency situation is present.



# Permits and Regulations\_\_\_\_\_Chapter 6

## General Laws of Massachusetts

### Chapter 128: Section 1A. Farming, agriculture, farmer; definitions

*“Farming” or “agriculture” shall include farming in all of its branches and the cultivation and tillage of the soil, dairying, the production, cultivation, growing and harvesting of any agricultural, **aquacultural**, floricultural or horticultural commodities, the growing and harvesting of forest products upon forest land, the raising of livestock including horses, the keeping of horses as a commercial enterprise, the keeping and raising of poultry, swine, cattle and other domesticated animals used for food purposes, bees, fur-bearing animals, and any forestry or lumbering operations, performed by a farmer, who is hereby defined as one engaged in agriculture or farming as herein defined, or on a farm as an incident to or in conjunction with such farming operations, including preparations for market, delivery to storage or to market or to carriers for transportation to market.*

The Massachusetts Department of Agricultural Resources (MDAR) provides regulatory assistance for the permitting of aquacultural facilities in the Commonwealth. **Producers should refer to the *Massachusetts Aquaculture Permits Guidance Document***, available at: <http://www.mass.gov/agr/aquaculture/guidance.pdf> or from the MDAR Aquaculture Coordinator’s office at (617) 312-2153

A variety of licenses and agencies provide regulatory influence on aquaculture operations. Completion and approval of applications may require considerable time and effort. Listed below are the relevant licenses, agencies and contact information.

Information on fees required for Massachusetts permits can be accessed at <http://www.mass.gov/dep/service/online/fees.htm>.

### Aquaculture Licenses

This information is summarized from the Massachusetts Division of Fisheries and Wildlife Regulations, 321 CMR 4.09 ([http://www.mass.gov/dfwele/dfw/cmr/dfw\\_cmr\\_400.htm](http://www.mass.gov/dfwele/dfw/cmr/dfw_cmr_400.htm)). A summary is located at: <http://www.mass.gov/czm/wpdfwreg.htm>.

Except in situations specifically allowed by fish and wildlife laws, it is illegal to possess, maintain, propagate, culture, or sell any fish without having a valid license in one of four classes:

#### Class 1 Private Waters License

A Class 1 Private Waters License is issued for non-commercial aquaculture. Fish may not be sold under a Class 1 Private Waters License. This license authorizes the license holder (i.e. individual, club, or association) to buy, possess, propagate, culture, and maintain fish for

personal use only. People may fish in a water body licensed as a Class 1 without a Massachusetts fishing license as long as they have written permission from the licensee.

### **Class 2 Public Waters Stocking License**

A Class 2 Public Waters stocking license authorizes the license holder to purchase, possess, propagate, culture, and maintain fish that are to be stocked into public waters. The terms and conditions of this license will be determined on a case by case basis. Fish may not be sold under a Class 2 Public Waters stocking license.

### **Class 3 Aquaculture License**

A Class 3 Aquaculture License authorizes the holder to propagate, culture, maintain, purchase and sell fish. Licenses are issued for three different types of facilities, with different specific requirements, depending on the species of fish to be grown. All Class 3 aquaculture facilities have four criteria in common: 1) they may not be located on great ponds or navigable waters; 2) they must be designed to allow the passage of anadromous fish that naturally or historically occur in that body of water; 3) they must be conspicuously posted; and 4) they must be exclusively controlled by the licensee.

Live fish may not be removed from any Class 3 facility without a valid license to stock or culture those fish. The seller must keep a record of the name, address, and license number of the buyer.

Although all aquaculture facilities are authorized to propagate, culture, and maintain fish, each type has different criteria to which it must adhere.

### **Class 6 Dealer's License**

A Class 6 Dealer's License allows the holder to possess, maintain and sell live or dead fish that were harvested or cultured legally. There are two common situations where this license is typically issued. First, this license will allow bait store owners to hold commercial bait species for sale. Second, grocery stores or restaurants that have a live tank of fish, often trout, will be able to operate under this license rather than having to obtain a Class 3 Aquaculture License. A Class 6 Dealer's License is not needed to sell carcasses that have already been processed and packaged legally.

#### **Issuing Agency**

Massachusetts Division of Fisheries & Wildlife  
251 Causeway Street  
Suite 400  
Boston, MA 02114-2104  
(617) 626-1591



## **Marine Aquaculture**

To grow marine finfish, a Special Permit issued by the Massachusetts Division of Marine Fisheries must be obtained and an annual activities report filed.

[http://www.mass.gov/dfwele/dmf/commercialfishing/permit\\_index.htm](http://www.mass.gov/dfwele/dmf/commercialfishing/permit_index.htm)

### **Issuing Agency**

Massachusetts Division of Fisheries & Wildlife  
251 Causeway Street  
Suite 400  
Boston, MA 02114-2152  
(617) 626-1591

## **Permits**

### **Importation Permit**

Individuals intending to bring species into Massachusetts must obtain an Importation Permit per Massachusetts regulation 321 CMR 2.15

- Importer must request a health certificate from the source of purchase. The importer may have to pay for the inspection.
- Mandatory 15 day waiting period
- Requirements are dependent on circumstances: imported must contact MDFW for specific requirements.

### **Issuing Agency**

MA Division of Fisheries & Wildlife  
251 Causeway Street  
Suite 400  
Boston, MA 02114-2104  
(617) 626-1591

### **Water Withdrawal Permit**

Aquaculture facilities withdrawing over 100,000 gallons per day for more than 30 days in any one year must possess a Water Withdrawal Permit.

- There is a 9 month waiting period.
- An initial permit and annual renewal fee is required.

### **Issuing Agency**

Department of Environmental Protection  
Watershed Planning & Permitting  
1 Winter Street  
Boston, MA 02108  
(617) 574-6882

## **Water Discharge Permits**

Aquaculture facilities discharging water into groundwater or surface waters require permits to comply with the Clean Water Act.

### **Surface Water Discharge Permits**

- Required to discharge into rivers, streams, ponds, springs, wetlands, estuaries, and coastal waters.
- Permits are required from both the Massachusetts DEP and the US EPA.

### **Non-process Waste Water Permit (Category BRP WM 13)**

- Permits are issued for five years.
- An application fee and annual compliance fee is required.

#### **Issuing Agency**

Department of Environmental Protection  
Division of Watershed Management  
627 Main Street  
Worcester, MA 01608  
(508) 792-7470

### **National Pollutant Discharge Elimination System (NPDES)**

All facilities that discharge wastewater directly from a point source (a discrete conveyance such as a pipe, ditch or channel) into a receiving water body (lake, river, and ocean) are must possess an NPDES permit. NPDES Permits are issued jointly by the US EPA and MA Department of Environmental Protection. While EPA does not require a fee, MDEP does.

#### **Issuing Agencies**

EPA New England  
1 Congress Street  
Suite 1100 (CMU)  
Boston, MA 02114  
(617) 918-1519

MA Dept. of Environmental Protection  
Division of Watershed Management  
1 Winter Street, Boston, MA 02108  
(617) 792-5749

**Note:** Facilities that discharge wastewater to a publicly owned treatment works, which in turn discharges into the receiving water body, are not subject to NPDES permits, but they are controlled by the national pretreatment program. For information, see:

*Introduction to the National Pretreatment Program* EPA-833-B-98-002

<http://www.epa.gov/npdes/pubs/final99.pdf>

**Groundwater Discharge Permit**

- Required to discharge facility water into the ground
- <http://www.mass.gov/dep/water/approvals/gwfaqs.htm>

**Issuing Agency**

Department of Environmental Protection  
Division of Watershed Management  
Groundwater Permitting Section  
1 Winter Street, Boston, MA 02108  
(617) 792-5749

**Dredge/ Fill Material Discharge**

- Discharge of dredge and fill materials into United States waterways must act in compliance with Clean Water Act.

**Issuing Agencies**

U.S. Army Corps of Engineers  
696 Virginia Road  
Concord, MA 01742  
(978) 318-8491

MA Department of Environmental Protection  
Division of Watershed Management  
627 Main Street  
Worcester, MA 01608  
(508) 792-7470

**Wetland Alteration Permit**

Development of facilities which alter in or near inland or coastal wetland resource areas require a Wetlands Permit in compliance with the Wetlands Protection Act.

- Filing fee is dependent on the project.
- The local Conservation Committee reviews plans and approves proposals.
- Appeals can be made to DEP Office of Watershed Management.

**Issuing Agencies**

Local Conservation Committees (contact town governments)

Department of Environmental Protection  
Office of Watershed Management  
Wetlands Program  
1 Winter Street  
Boston, MA 02018  
(617) 292-5695

## **Oil Pollution Prevention Regulation**

Title 40 of the Code of Federal Regulations, Part 112

Any facility with a total above ground oil storage capacity greater than 1320 gallons and located so that oil discharge can reach navigable waters or shore lines must have a fully implemented Spill Prevention, Control, and Countermeasure (SPCC) Plan, certified by a licensed professional engineer.

The SPCC Plan should address such issues as spill prevention and control measures, containment measures, periodic integrity and leak testing of containers valves and piping, employee training and spill contingency procedures. A written commitment of manpower, equipment, and materials required to quickly remove any quantity of oil discharged that may be harmful should be provided.

Oil pollution regulations and SPCC plans can be found at the EPA website:

<http://www.epa.gov/oilspill/spcc.htm>

## **Federal (EPA) Storm Water Permit for Construction Projects**

Any project that disturbs one acre or more of land in which storm water could run off the site and reach surface water requires a storm water permit. See:

<http://epa.gov/region01/npdes/stormwater/assets/pdfs/permit%20basics%2003%20final.pdf>

## **Food Processing**

If fish are to be killed and sold by the producer as a food product, Commonwealth of Massachusetts Regulations, 105 CMR 533.000 – Fish and Fisheries Products must be followed (see: <http://www.mass.gov/Eeohhs2/docs/dph/regs/105cmr533.pdf>). Processors should obtain a Whole/Retail Operations Inspection Request (available from the Division of Marine Fisheries (<http://www.mass.gov/dfwele/dmf/dealers/dealerapp.pdf>) and submit the completed application to the Massachusetts Department of Public Health. An appropriate HACCP plan is required (see References, Chapter 8 in this document, for assistance on HACCP). It is recommended that the local board of health is consulted before initiating a food processing facility.

### **Issuing Agency**

Massachusetts Department of Public Health  
Division of Food and Drugs  
305 South Street  
Jamaica Plain MA 02130-3597  
(617) 983-6774  
Requests may be faxed to (617) 983-6770

## **Predator Control**

### **Birds**

The Migratory Bird Treaty Act authorizes the issuance of permits to control depredating birds such as raptors, provided certain criteria are met. A description of the area where the depredations are occurring, the nature of the interests being injured, the extent of the injury, and a description of the particular species committing the injury is required. A depredation permit does not grant the killing of migratory birds unless specifically authorized and stated on the permit. Title 50, CFR, Part 21.41 explains the depredation permit process. For specific information, see:

<http://www.entm.purdue.edu/wildlife/Code%20of%20Federal%20Regulations.htm>

### **Issuing Agency**

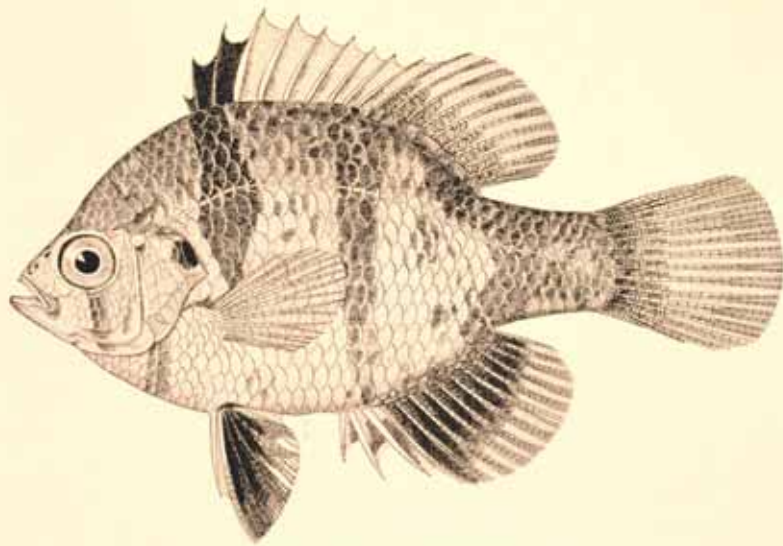
U.S. Fish and Wildlife Service  
Northeast Regional Office  
Attention: Migratory Bird Permit Office  
300 Westgate Center Drive  
Hadley, MA 01035-9589  
(413) 253-8200

### **Other species**

Massachusetts General Law Chapter 131 section 37 (<http://www.mass.gov/legis/laws/mgl/131-37.htm>) makes allowances for citizens experiencing damage due to wildlife. In summary the law states, “an owner or tenant of land, or any member of his immediate family or person permanently employed... may upon such land: ... kill or attempt to kill, by means other than poisoning or snare, any mammal which he finds damaging his property except uncultivated plants.” Producers remain subject to all other state laws or town ordinances concerning the use of trap types (e.g. M.G.L Chapter 31, Section 80a, which prohibits body-hold traps <http://www.mass.gov/legis/laws/mgl/131-80a.htm>) and the discharge of firearms, such as no discharge closer than 150 feet of a road, or discharge within 500 feet of a house or occupied building without the occupant’s permission. Once the animal has been destroyed, a letter stating the time, location, and number and sex of the animals killed or wounded should be sent or faxed to MDFW. Snapping turtles may be taken without a permit.

### **Issuing Agency**

Massachusetts Division of Fisheries and Wildlife  
Field Headquarters  
One Rabbit Hill Road  
Westborough, MA 01581  
Fax (508) 792-7275  
Tel (508) 792-7270



THE BLACK-BANDED SUNFISH.

*Mesogemmus chatahui* (Baird), Gil.

Preserved by H. S. Todd, from No. 3024 U. S. National Museum, collected at Treason, N. Z., 1875, by Dr. C. F. Abbott.

PLATE 101

# Glossary Chapter 7

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**Aeration** – To supply with air or expose to air circulation. Typically used to increase dissolved oxygen (D0).

**Alkalinity** – Also called “buffering capacity.” Measured as mg/L  $\text{CaCO}_3$  it is the ability of a solution to resist changes in pH, which can stress fish. Buffers (carbonates and bicarbonates in water) absorb excess acids and bases. In most aquaculture systems alkalinity should be maintained above 50 mg/L.

**Anesthetic** – Chemical approved and used for handling fish to reduce activity and vulnerability to damage.

**Aquarium Trade Fish** – Also known as “ornamental fish.” Fish species (e.g. koi, goldfish, guppies) typically reared by hobbyists in small ponds or small RASs. These fish are raised primarily for aesthetics.

**Aquifer** – Underground bed or layer yielding ground water for wells and springs etc.

**Artesian Well** – A well drilled through a water impermeable strata into strata that receive water from a higher altitude so that pressure forces water to flow upward.

**Bacteria** – Any of the unicellular prokaryotic microorganisms of the class Schizomycetes, which vary in morphology, oxygen and nutritional requirements, and motility. They may be free-living, saprophytic, or pathogenic in plants or animals.

**Biofilter** – Component of RAS system which houses beneficial bacteria to assist in the nitrogen cycle.

**Biological Oxygen Demand (BOD)** – The amount of oxygen required by aerobic microorganisms to decompose the organic matter in a sample of water.

**Cage Culture** – The practice of raising fish in supported, relatively small enclosures of plastic mesh that are anchored in a body of water. Cage culture provides easier access to fish when feeding, sampling, and harvesting; and also facilitates use of waters otherwise unsuitable to aquaculture such as rivers, lakes, and ponds with irregular bottoms.

**Chemical Oxygen Demand (COD)** – the amount of oxygen consumed by a liter of solution: a measure of the amount of organic compounds in water.

**Colloid** – A suspension of finely divided particles in a continuous medium from which the particles do not settle out rapidly and are not readily filtered.

**Constructed Wetland** – Man-made habitat used to facilitate the cleansing of wastewater before its reintroduction to local watersheds. Plants routinely serve as primary filters and secondary trickling beds; although other organisms such as bivalve mollusks, crayfish and annelids can also rejuvenate water by removing suspended solids.

**Culturist** – A fish farmer.

**Deterrent Method** – Any process implemented to keep predators away from fish stocks

**Dissolved Oxygen (DO)** – Level of oxygen in water and available for living organisms. Measured as mg/l, ppm, or percent saturation.

**Drug** – A substance used in the diagnosis, treatment, or prevention of a disease

**Field Border** – A strip of permanent vegetation established at the edge of field, consisting of grasses, legumes and/or shrubs.

**Filter Strips** – Sometimes referred to as grass filter strips or grass buffer strips, areas that are seeded to close-growing or sod forming grasses at locations where runoff water leaves a field within and next to cropland. They are designed to filter out the sediment, organic material, nutrients, and chemicals carried in runoff water.

**Flow Through System (FTS)** – Aquaculture system where water is continuously supplied and discharged from the culture area such as a raceway.

**Flocculant** - A chemical that causes suspended particles in liquids to aggregate and then participate because of their accumulated mass. They are used to improve the sedimentation in water, reducing cloudiness.

**Game Fish** – Category of large, predatory fish sought by recreational anglers. (While panfish and rough fish are also sought by anglers, they are not considered to be game fish.)

**Groundwater** – Subsurface water which supplies wells and springs.

**HACCP** – (Hazard Analysis and Critical Control Points) – A management system that identifies, evaluates and controls hazards that are significant for food safety. A mandatory Food and Drug Administration (FDA) seafood inspection program required by fish processors, wholesalers, and retailers

**Oxygenation** – The act of adding supplemental oxygen to a body of water, in contrast to aeration when atmospheric air is used to add oxygen to water.

**Parasites** – Organisms that uses another organism as a host for an unspecified length of time.



**pH** – A measure of the concentration of hydrogen ions present in a body of water indicating acidity. Measured on a scale from 1 to 10; 7 is neutral.

**Pond Culture** – The raising of fish in small bodies of static water.

**Predator** – Any animal preying on or possessing a threat to stocks.

**Raceway** – Culture system which typically uses gravity to move water through system. The inlet is located higher than the outlet and the base of these typically rectangular units that slopes downward, supplying a rapid flow of water.

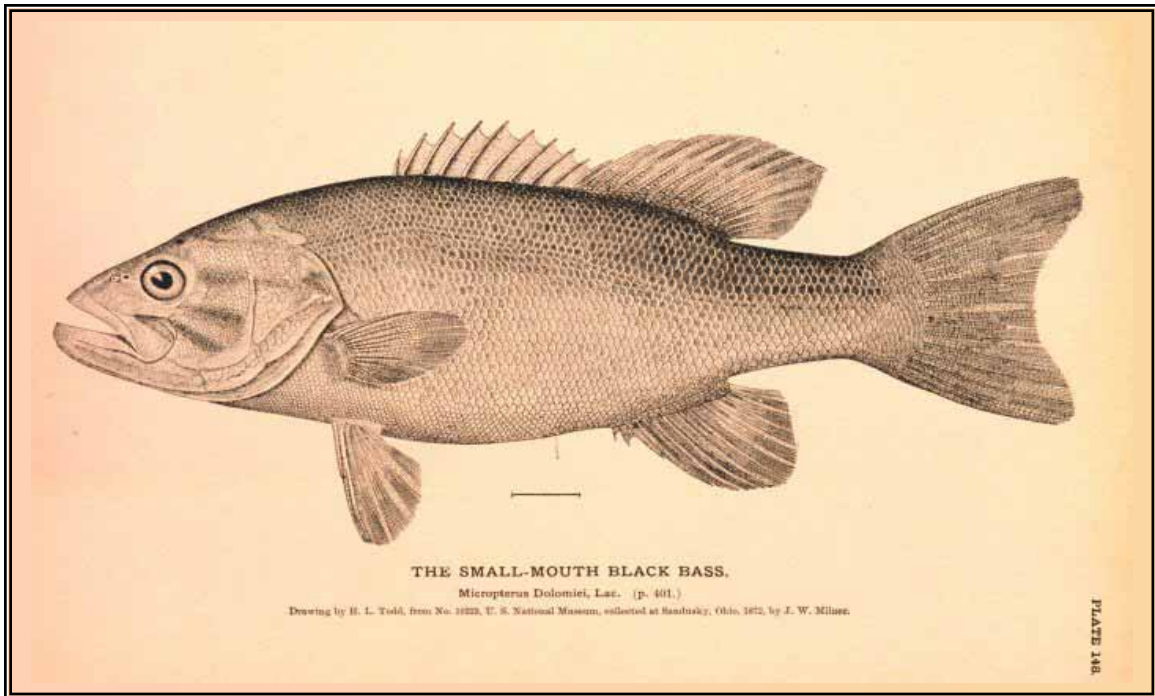
**Recirculating Aquaculture System (RAS)** – A sophisticated fish rearing system which reuses water and utilizes less than 10% replacement water daily. Systems typically include a fish holding unit, sediment removal system, biological filter, aeration or oxygenation, pump and plumbing. All nutritional and environmental requirements for the species cultured are provided by the grower.

**Settling Pond** – Basin of reduced flow designed to collect solid waste contained in discharge waters from a culture system.

**Turbidity** – A measure of the clarity of water. Turbidity is closely related to total suspended solids (TSS), but also includes plankton and other organisms as well as dissolved material in water, coloration.

**Viral** – of or relating to an infectious disease caused by a virus.

**Water Quality** – The condition of water as measured by a number of parameters including pH, ammonia, alkalinity, etc.



# References Chapter 8

**The following publications provided guidance in developing the lists of best management practices in this publication:**

- Lutz, Greg C. Romaine, Robert P. Sanders, Fred S. 2003. Aquaculture Production Best Management Practices. Louisiana State University. <http://www.lsuagcenter.com>
- Tucker, Craig. Best Management Practices for Flow-Through, Net-Pen, Recirculating, and Pond Aquaculture Systems. Mississippi State University.
- Hartleb, Christofer F., Malison, Jeffrey A. 2005. Best Management Practices for Aquaculture in Wisconsin and the Great Lakes Region. University of Wisconsin. <http://www.seagrant.wisc.edu/aquaculture/>
- Guide to Drug, Vaccine, and Pesticide Use in Aquaculture*. 2004 (revised). The Federal Joint Subcommittee on Aquaculture Working Group on Quality Assurance in Aquaculture Production <http://aquanic.org/jsa/wgqaap/drugguide/drugguide.htm>

**Additional information may be found in the following publications:**

- Aquaculture Biosecurity: Prevention, Control and Eradication of Aquatic Animal Disease*. by David Scarfe, Cheng-Sheng Lee, Patricia J. O'Bryen. 2005. Blackwell Publishing and the World Aquaculture Society. 188 pp.
- Encyclopedia of Aquaculture*. R. Stickney (ed.). 2000. Wiley-Interscience. 1063 pp.
- Fish Hatchery Management*, 2nd Edition. 2002. G A Wedemeyer (ed.). Western Fisheries Research Center, Biological Resources Division, US Geological Survey. 751 pp.
- An Introduction to Water Chemistry in Freshwater Aquaculture*. 1993. by J.K. Buttner, R.W. Soderberg and D.E. Terlizzi. Northeastern Regional Aquaculture Center Fact Sheet no. 170. 4 pp. <http://www.umass.edu/aquaculture/resources/pdf/nrac170.pdf>
- Management of Farm Ponds in Pennsylvania*. 2000. Pennsylvania State University Extension Service. 30 pp. <http://pubs.cas.psu.edu/FreePubs/pdfs/uh137.pdf>
- Managing FlowThrough Systems*. Alabama BMP 20. USDA NRCS/Auburn University. <http://www.aces.edu/dept/fisheries/aquaculture/pdf/G20ManagingFlowThroughSystems.pdf>
- New England Salmonid Health Guidelines*. New England Salmonid Health Committee. 2001. Contact Massachusetts Division of Fisheries and Wildlife.
- Ponds – Planning, Design and Construction*. USDA NRCS Agriculture Handbook 590. <http://www.in.nrcs.usda.gov/pdf%20files/PONDS.PDF>

*Pond Management – An in depth response to frequently asked questions by pond owners and managers.* 2004.  
By Michael Gaden. Michigan State University Extension.  
<http://web1.msue.msu.edu/waterqual/WQWEB/Pondmgmt.pdf>

*Recirculating Aquaculture Systems.* 2<sup>nd</sup> Edition. 2002. by M. B. Timmons, J. M. Ebeling, F. W. Wheaton, S. T. Summerfelt, B.J. Vinci.

*Sanitation Practices for Aquaculture Facilities.* 2006. R. Francis-Floyd. <http://edis.ifas.ufl.edu/AE081>

**The following websites provide information and links concerning aquaculture practices:**

**Northeast Regional Aquaculture Center (NRAC)**

<http://www.nrac.umd.edu/>

**Western Massachusetts Center for Sustainable Aquaculture (WMCSA)**

<http://www.umass.edu/aquaculture/>

**Northeastern Massachusetts Aquaculture Center (NEMAC)**

<http://www.salemstate.edu/biology/aquaculture/>

**Southeastern Massachusetts Aquaculture Center (SEMAC)**

<http://www.umassd.edu/semap/partner/49.cfm>

**Massachusetts Department of Agricultural Resources - Aquaculture White Paper**

<http://www.mass.gov/czm/wptoc.htm>

**NPDES Water Permit Program in New England.** US Environmental Protection Agency.

<http://epa.gov/region01/npdes/index.html>

**Generic HACCP Plan.** University of California.

<http://seafood.ucdavis.edu/haccp/plans/fishwhol.htm#C3>

**Steps in Developing Your HACCP Plan, US Food & Drug Administration.**

<http://www.cfsan.fda.gov/~acrobat/haccpc02.pdf>

**Aquaculture Network Information Center** <http://aquanic.org/>

**Guide to Drug, Vaccine, and Pesticide Use in Aquaculture**

<http://aquanic.org/jsa/wgqaap/drugguide/drugguide.htm>

**U.S. Food and Drug Administration, Center for Veterinary Medicine - Aquaculture**

<http://www.fda.gov/cvm/aqualibtoc.htm>

**Western Massachusetts Center for Sustainable Aquaculture  
University of Massachusetts Extension  
Agricultural Engineering Building  
250 Natural Resources Way  
University of Massachusetts  
Amherst MA 01003**

**[www.umass.edu/aquaculture](http://www.umass.edu/aquaculture)**